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Spatial scales of exploitation among populations of demersal scalefish: implications for management.

Part 2: Stock structure and biology of two indicator species, West Australian dhufish (*Glaucosoma hebraicum*) and pink snapper (*Pagrus auratus*), in the West Coast Bioregion

Final FRDC Report - Project 2003/052

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Contents

Non technical summary **1**

Objectives 1

Outcomes achieved 2

Acknowledgements 4

1.0 Introduction **5**

1.1 Background 5

1.2 Need 6

1.3 Objectives 7

1.4 Structure of report 7

2.0 Study species, description of the fishery and sampling methods **9**

2.1 Indicator species studied 9

2.1.1 West Australian dhufish 9

2.1.2 Pink snapper 9

2.2 Description of the fishery 10

2.3 Study sites 10

2.4 Sample collection and processing 12

2.4.1 Sample collection 12

2.4.2 Sample processing 13

2.4.3 Otolith preparation 13

3.0 Level of intermixing among populations **14**

3.1 Introduction 14

3.1.1 Pilot study 15

3.2 Methods 16

3.2.1 Dhufish 16

3.2.2 Pink snapper 16

3.2.3 Preparation of the otoliths for IRMS analysis 16

3.2.4 Stable isotope analysis 16

3.2.5 Environmental variables and proxy temperature history 17

3.2.6 Statistical analysis 17

3.3 Results 17

3.3.1 Salinity and temperature 17

3.3.2 Dhufish 17

3.3.3 Pink snapper 18

3.4 Discussion 23

3.4.1 Dhufish 23

3.4.2 Pink Snapper 23

4.0 Regional comparisons of the reproductive biology of dhufish *Glaucosoma hebraicum* in the West Coast Bioregion **25**
4.1 Introduction 25
4.2 Methods 26
4.2.1 Annual reproductive cycle 26
4.2.2 Batch fecundity 27
4.3 Results 28
4.3.1 Gonad morphology 28
4.3.2 Length at maturity 29
4.3.3 Annual and regional trends in reproductive cycles 29
4.3.4 Batch fecundity 33
4.4 Discussion 35

5.0 Spatial and temporal comparisons of the age and growth of dhufish *Glaucosoma hebraicum* in the West Coast Bioregion **36**
5.1 Introduction 36
5.2 Methods 36
5.2.1 Otolith interpretation 36
5.2.2 Age determination 38
5.2.3 Growth 38
5.2.4 Environmental variables 39
5.3 Results 39
5.3.1 Contribution of fish samples from each sector 39
5.3.2 Bias and precision of opaque zone counts 40
5.3.3 Length and age compositions 42
5.3.4 Growth 45
5.3.5 Recruitment and environmental variables 48
5.4 Discussion 50
5.4.1 Age compositions and growth 50
5.4.2 Variations in year class strength and environmental variables 51

6.0 Regional comparisons of the reproductive biology of pink snapper *Pagrus auratus* in the West Coast Bioregion **53**
6.1 Introduction 53
6.2 Methods 54
6.2.1 Annual reproductive cycle 54
6.2.2 Length and age at maturity 55
6.3 Results 55
6.3.1 Annual reproductive cycles 55
6.3.2 Relationship between spawning and water temperature 59
6.3.3 Length and age at maturity 59
6.3.4 Spatial distribution of spawning in the Metropolitan region 62
6.4 Discussion 64

7.0 Regional comparisons of the age and growth of *Pagrus auratus* in the West Coast Bioregion **66**
7.1 Introduction 66
7.2 Methods 66
7.2.1 Otolith interpretation 66
7.2.2 Validation of annual formation of opaque zones on otoliths..... 68
7.2.3 Age determination 68
7.2.4 Growth 68
7.3 Results..... 69
7.3.1 Contributions of samples from each sector 69
7.3.2 Bias and precision 70
7.3.3 Marginal increments analysis 71
7.3.4 Length and age composition..... 73
7.3.5 Growth 76
7.4 Discussion..... 79
8.0 Assessment of management options **80**
8.1 Introduction..... 80
8.2 Activities and outcomes..... 80
8.2.1 Stakeholder meetings..... 81
8.2.2 Stakeholder views and perceptions..... 81
8.2.3 Internal stakeholders: contribution to management and policy development..... 83
8.2.4 Conceptual model to assess alternative management options..... 86
8.3 Summary of the development of an optimal management strategy..... 86
8.3.1 Prior to completion of the stock assessments (up to 2007)..... 87
8.3.2 After completion of the stock assessments..... 89
8.4 Conclusions..... 94
9.0 Project summary **95**
9.1 Benefits and adoptions..... 95
9.1.1 Commercial fishery..... 95
9.1.2 Integrated Fisheries Management..... 95
9.2 Further development..... 95
9.2.1 Recruitment and spatial dynamics of early life history stages..... 95
9.2.2 Stock assessment and monitoring..... 96
9.3 Planned outcomes 97
9.4 Conclusions..... 97
10.0 References **99**
11.0 Appendices **105**
Appendix 1. Community Consultation desk top study 105
Appendix 2. Stakeholder meetings 108

Appendix 3. Petition to the minister 113
Appendix 4. Draft Management Proposals for the Metropolitan Recreational Fishery 115
Appendix 5. Preliminary development of a management strategy evaluation model... 125
Appendix 6. Fisheries Management Paper 225 – Managing the Recreational Catch of Demersal Scalefish on the West Coast 131
Appendix 7. Staff 181

Non technical summary

Spatial scales of exploitation among populations of demersal scalefish: implications for management.
Part 2: Stock structure and biology of two indicator species, West Australian dhufish (*Glaucosoma hebraicum*) and snapper (*Pagrus auratus*), in the West Coast Bioregion

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Objectives

1. To examine the level of intermixing among populations of both pink snapper and dhufish along the West Coast to determine the appropriate geographical scales for management
2. To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction.
3. To evaluate the spatial variation in the exploitation status of dhufish, pink snapper and baldchin groper within the West Coast Bioregion. Note: because the work undertaken in the FRDC Project will contribute to management of the entire West Coast Demersal Scalefish Fishery, this objective was expanded to include a third species, baldchin groper.
4. To develop a suite of alternative management scenarios to assist the multiple fishing sectors of the Bioregion to select and adopt an optimal management strategy.

Outcomes achieved

Scientific advice has been produced to the stakeholders, managers and the independent expert panels involved in the commercial management process and Integrated Fisheries Management process for the West Coast Demersal Scalefish Fishery (i.e. in the West Coast Bioregion, WCB)

Comprehensive advice to managers included

- the most appropriate spatial scale(s) of management (commercial and recreational sectors) for pink snapper and dhufish
- regional differences in the age structure and biology of pink snapper and dhufish within the WCB
- the importance of Cockburn Sound to pink snapper in the WCB to the Cockburn Sound Management Council and Fremantle Port Authority (developers in CS)

The results from this study were used in regional stock assessments for snapper and dhufish in the WCB (provided in Part 1 of this report)

Dhufish

West Australian dhufish is endemic to shelf waters of south-western Western Australia (WA). In contrast, snapper (known as "pink snapper" in WA) has a continuous distribution around the southern coastline of mainland Australia and in New Zealand. Dhufish and snapper are the two most important exploited demersal scalefish species in the West Coast Bioregion (WCB) of WA, which extends from Kalbarri (27°S) to Augusta (35°S). This study examined regional variation in the biology of the two species, their stock structure and assessed the status of these stocks in the WCB. Part 1 of this report focussed on the stock assessment, which utilized the results from the research on biology and stock structure. This second part of the report presents the full results of the biology and stock structure.

The maximum recorded ages of dhufish in this study were 24, 29 and 32 years in the North, Metropolitan and South zones of the WCB, respectively. Therefore, over the last decade the maximum observed age of dhufish has dropped 9 years from 41 to 32 years old, and the proportion of older dhufish (> 13 years of age) in the catches has decreased from 28% to 9%. This lack of older fish is indicative of recent depletion. While large fish are still being caught in the fishery, they are not necessarily old fish because length-at-age varies greatly in older fish. The growth rate of dhufish did not vary between zones within the WCB.

Adult dhufish do not generally move significant distances from their area of residence; the resultant limited mixing along the coast through the WCB indicates that some level of zonation is required for the management of the stock to avoid localised depletion. Their primary mode of dispersal is most likely through current-driven larval transport. The reproductive strategy of dhufish involves a complex social system. Dhufish males attain a larger size than females and the exceptionally small size of the male gonads suggest that dhufish are pair or small group spawners. Spawning events appear to be dispersed throughout the distribution of this species. *Dhufish spawn* from November to March. The fecundity (numbers of eggs produced per fish) increased with length and the frequency of spawning was lower in smaller females. The recruitment of dhufish appears to be relatively consistent between years but does show some variability in the more southern latitudes.

Pink snapper

The maximum ages of snapper recorded in this study were 26, 29 and 33 years in the North, Metropolitan and South zones, respectively. The maximum ages recorded for this species are 38 years in Australia (from the south coast of WA) using sectioned otoliths and 60 years in New Zealand using burned cross-sections of otoliths. Most of the catch in the WCB is comprised of individuals < 8 years of age (except for Cockburn Sound). The dominant age classes in the north of the bioregion ranged from 3 to 6 years, compared to 4 to 8 years in the south. The age composition of snapper in the Metropolitan zone was bimodal, with fish associated with the spawning aggregations in the nearshore marine embayment of Cockburn Sound being predominantly > than 6 years old. Given that snapper can live to > 30 years of age, the low numbers of older fish in all zones (except the spawning aggregations sites in the Metropolitan region) is indicative of a stock that is heavily fished.

There were regional differences in the timing of the spawning period and growth of snapper. Growth rates of snapper were lower in the north than in the two more southerly zones. Due to these differences, length at maturity varied among regions, with half of females in the North reaching maturity by 490 mm TL (5.4 years) compared to 580 mm TL (5.5 years) in the Metropolitan zone.

Snapper spawn from May to November in the North, October to December in Cockburn Sound (Metropolitan zone), and October to January in the South region. As the nearshore marine embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound in the Metropolitan zone are the only recognized locations in the WCB where large spawning aggregations of snapper occur annually, it is likely that spawning at these inshore locations is a major source of recruitment of snapper in the WCB. The currents within these nearshore marine embayments act to retain the eggs and larvae of snapper, and previous research has shown juveniles remain in these areas for up to the first 14 months of their life. Cockburn Sound, in particular, is therefore not only the most important spawning site for snapper in the WCB but is also a critical nursery habitat for this species.

Evidence from this study suggests that most of the movement from major nursery areas to those occupied by the mature stock is undertaken by immature fish, and that adult snapper do not migrate along the coast throughout the WCB. Adults in the Metropolitan zone do, however, migrate seasonally inshore to spawn in Cockburn Sound. Alongshore dispersal of snapper may rely upon movement of juveniles, for example, out of inshore embayments in the Metropolitan region. Recruitment would also arise from spawning activity elsewhere in the WCB, but in oceanic waters rather than marine embayments; in such cases there would be greater potential for alongshore dispersal of eggs and larvae.

Management Options

During the course of this project the results on the biology and stock structure of dhufish and snapper have been presented to a range of stakeholders at public meetings to provide the basic tenets of fish biology and how these relate to the interpretation of scientific results and fishery management options. This direct communication with stakeholders helped increase their understanding of fisheries science and management. This developed into an ongoing cycle of iterative provision of scientific advice, development of management options and consideration of stakeholder opinions. This cycle has continued up to the present time, with the results from this study continuing to provide the scientific basis for objective consideration of a range of potential management measures required to meet the sustainability needs of the key west coast demersal scalefish resources.

Key Words

Pink snapper, snapper, West Australian dhufish, stock structure, reproduction, spawning, age, growth, management.

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1.0 Introduction

1.1 Background

The Department of Fisheries, Western Australia has divided its vast marine jurisdiction into four bioregions. The West Coast Bioregion extends from Kalbarri (27°00'S) to Augusta (115°30'E), adjacent to the major population centres of Western Australia. The West Coast Bioregion supports major commercial demersal finfish fisheries including the West Coast Demersal Gillnet and Demersal Longline Interim Managed Fishery and the West Coast Demersal Scalefish Fishery (WCDSF) that encompasses management of commercial, charter boat and recreational fishing of demersal scalefish within the West Coast Bioregion.

Considering the social and economic importance of the various fisheries that target demersal scalefish in the West Coast Bioregion and the need for resource allocation within the bioregion (Rogers & Curnow 2002), the integrated management of all sectors of the scalefish fishery in the West Coast Bioregion is a significant challenge for the Department of Fisheries, Western Australia. The most pressing allocation issue at present concern the stocks of demersal scalefish as several of the key demersal fish species are heavily exploited. This problem of allocation within and between sectors is not unique to Western Australia and if the approaches developed in this project are successful, they could be applied to other important, geographically extensive fisheries in Australia.

The West Coast Bioregion is the major focus for recreational boat-based fishing including a growing charter boat industry. In 2005/06, the West Coast Bioregion supported around 701,000 recreational boats hours and approximately 26,500 charter boat fisher days in addition to around 12,500 active commercial fishing days. The offshore reef species in the West Coast Bioregion, West Australian dhufish (*Glaucosoma hebraicum*) pink snapper (*Pagrus auratus*) and baldchin groper (*Choerodon rubescens*) are under high recreational and commercial fishing pressure (StJohn & King 2006). Commercial fishers target these species differently across the West Coast Bioregion. Near the metropolitan area, dhufish are the primary target whereas near Geraldton, dhufish and pink snapper form part of a suite of prize species, including baldchin groper, coral trout and lethrinids that attain high market prices.

Dhufish and pink snapper comprise nearly half the commercial catch of west coast demersal scalefish and for recreational fishers are some of the most frequently line-caught species. In 2005/06 the largest proportion of the total catch of dhufish was boat-based recreational (48.5%) followed by commercial (all methods, 47.5%) and then charter boats (4%). Pink snapper commercial fishing accounted for 80% of the total catch, followed by recreational (16%) and charter boat (4%) catches. Baldchin groper commercial fishing accounted for 46% of the total catch, followed by recreational (45.5%) and charter boat (8.5%) catches. A preliminary analysis of dhufish catch curves for the mid 1990s in Hesp *et al*. (2002) indicated that fishing mortality may already have been high and confirmed the need for more detailed stock assessments within the bioregion. Also, anecdotal evidence from fishers targeting dhufish clearly indicates that shifts in fishing pressure to “new” areas have occurred in response to localized depletion. A workshop on dhufish held in 2004 highlighted concerns held by members of all sectors for dhufish sustainability (Pagano & Fuller 2006).

To support the development of feasible management arrangements in the West Coast Bioregion, there is a need for an improved understanding of the basic biology and population structure as well as of the levels of exploitation throughout the bioregion of the key indictor species. The biology of dhufish has been studied previously (Hesp *et al.* 2002) which resulted in useful age and reproductive information. For pink snapper, there was little information on their biology south of Shark Bay prior to the completion of a PhD study as part of this project; preliminary data had indicated that biological parameters, such as growth rates and reproductive cycle, vary strongly with latitude. The biology of baldchin groper has been published (Fairclough 2005; Nardi *et al.* 2006). This project aims to build on existing knowledge of dhufish and pink snapper, supplementing it with additional biological research where necessary, and thus provide the basis for regional stock assessments for both species.

Regional stock assessments should consider any regional variations in the biological parameters of these demersal scalefish stocks. Given the varying levels of fishing pressure on demersal scalefish throughout the West Coast Bioregion and the potentially low levels of fish movement between areas within the bioregion, these assessments will need to address the question of spatial dynamics of the populations and the potential need for spatial management. Regardless of their genetic variability, for fisheries management purposes stocks are considered discrete when their mixing rates are low. In such cases, the behaviour of the fishing fleet(s) targeting a stock may dictate that some level of spatial management is required.

Information on age, growth and reproduction of the species in sub-regions of the West Coast Bioregion will be used in conjunction with regional catch and effort data to prepare regional stock assessments (see Part 1 of this project). Spatial dynamics of populations within the bioregion will be assessed using otolith microchemistry and other information that becomes available. Thus, at the end of the biological research, the Department of Fisheries, Western Australia will have a good understanding of the differences in productivity and exploitation among the key indictor species in the West Coast Bioregion. This information will provide the basis for developing management arrangements that may include measures to reflect the spatial dynamics of both the fish and the fishers.

Recreational and commercial fisheries pose different challenges for management. The commercial fishery is limited by the number of vessels, however, latent fishing effort is many times greater than the actual expended effort. In contrast, recreational fishing effort is largely unconstrained and, without management, could increase indefinitely along with the human population. Currently, catches of key species in the West Coast Bioregion are controlled by size limits for all sectors and recreational bag limits, but these fishing regulations are proving to be inadequate for deepwater species because many undersize fish do not survive after their release.

1.2 Need

To address the urgent issue of potential over-exploitation of reef-fish resources, the Western Australian Government commissioned the Wetline Review to bring Western Australian's wetline fisheries under more effective management, beginning with the West Coast Bioregion. Also, the finfish stocks on the West Coast Bioregion are undergoing Integrated Fisheries Management that will allocate the fish resources equitably amongst all users. The key issues are commercial and charter fishing viability, ongoing enjoyment of recreational fishing by the majority of Western Australian's population, provision of local world-class table fish for the non-fishing public and equitable allocation of resources among all sectors. The key needs for management of the west coast demersal scalefish fishery are:

- A better understanding of the spatial scales of the key indicator species populations along the West Coast Bioregion to determine their appropriate geographical scales for management.

- Knowledge of the regional variation in the biology of the key indicator species along the West Coast Bioregion.
- Estimating the exploitation status of the stocks of the key indicator species.
- To ensure that sustainability of the resource is the foundation of all management options by educating the stakeholders about the biology and the exploitation of the scalefish resources and by involving them in the management process.

1.3 Objectives

The four main objectives of this study were to:

1. To examine the level of intermixing among populations of both pink snapper and dhufish along the West Coast to determine the appropriate geographical scales for management
2. To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction.
3. To evaluate the spatial variation in the exploitation status of dhufish, pink snapper and baldchin groper within the West Coast Bioregion. Note: because the work undertaken in the FRDC Project will contribute to management of the entire West Coast Demersal Scalefish Fishery, this objective was expanded to include a third species, baldchin groper.
4. To develop a suite of alternative management scenarios to assist the multiple fishing sectors of the Bioregion to select and adopt an optimal management strategy.

1.4 Structure of report

This report is divided into two parts, the structure of which is shown in Figure 1.1. Part 1 of the report addresses the third objective, and is an evaluation of the spatial variation in the exploitation status of key indicator species captured in the West Coast Demersal Scalefish Fishery. Part 2 of the FRDC report examines the stock structure and regional biology of the two most important demersal fish species in this fishery and is divided into several chapters. Chapter 2 provides a description of the West Coast Demersal Scalefish Fishery, summarizes the known biology of the study species and describes general methods. Objective 1 is addressed in Chapter 3. The next four chapters address Objective 2. The biology of dhufish and pink snapper are provided in Chapters 4 and 5 respectively, while the reproductive biology for the two species are documented in Chapters 6 and 7 respectively. Objective 4, adopting an optimal management strategy, is addressed in Chapter 8. The project summary (Benefits and Adoptions, Further Development, Planned Outcomes and Conclusions) is provided in Chapter 9.

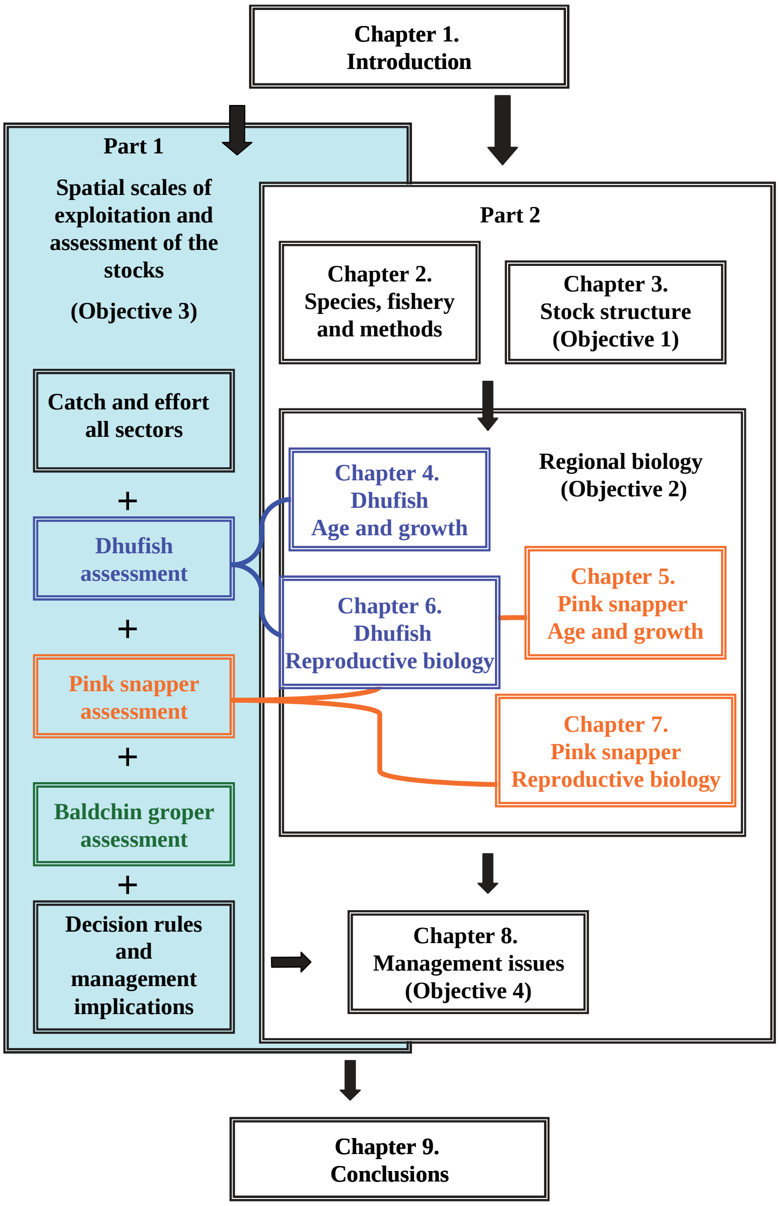

Figure 1.1. Flow diagram of structure of FRDC reports Part 1 and 2.

2.0 Study species, description of the fishery and sampling methods

2.1 Indicator species studied

2.1.1 West Australian dhufish

The West Australian dhufish, *Glaucosoma hebraicum* (Richardson 1845), is one of four members of the Glaucosomidae (McKay 1997) commonly known as pearl perches. The species is endemic to the coastal waters of the west coast of Western Australia and is found from Shark Bay (26°S, 113°E) to the Recherche Archipelago (34°S, 122°E) (Hutchins & Swainston 1996; McKay 1997). Within this range, *G. hebraicum* are most abundant between the Abrolhos Islands and Cape Naturaliste.

Glaucosoma hebraicum are closely associated with reef type habitat throughout their range, inhabiting coral reefs at the Abrolhos Islands and rocky limestone reefs in the temperate waters of the lower west coast. As a large demersal teleost, *G. hebraicum* represents an important component of the endemic fauna of southwest Australia (Wilson & Allen 1987). Juveniles (0+) recruit to hard substrata adjacent to rocky reefs. Hesp and Potter (2000) trawled very small *G. hebraicum* (< 150mm TL) from hard substrata near reefs 27–33 m in depth. The reefs adjacent to these areas are inhabited by adult *G. hebraicum* (> 300 mm TL, 3+ and older, Hesp & Potter 2000). Fish of intermediate size (150-300 mm TL) and age (1+ and 2+) have rarely been observed or caught (Hesp *et al.* 2002). *Glaucosoma hebraicum* is a slow growing and long-lived species (maximum age 40+ years, Hesp *et al.* 2002) and therefore vulnerable to over-exploitation. *Glaucosoma hebraicum* are highly valued by both the commercial and recreational sectors in WA because of their larger size, good eating qualities and high economic value.

Some aspects of the biology of *G. hebraicum* have been previously studied (Hesp *et al.* 2002). While this research was focused on *G. hebraicum* in the Metropolitan region, Hesp *et al*. (2002) also examined some fish from Geraldton (within the North region in this study). This project is the first to study the biology of *G. hebraicum* from the main fishing locations in the West Coast Bioregion.

2.1.2 Pink snapper

Pink snapper, *Pagrus auratus* (Bloch & Schneider, 1801), is a member of the Sparidae. In this study, we follow Paulin's (1990) redescription of the species as *P. auratus* for both northern hemisphere red sea bream, *P. major,* and the southern hemisphere, Australasian populations of snapper formerly known as *Chrysophrys auratus*.

Pagrus auratus is widely distributed throughout the warm-temperate and sub-tropical waters of the Indo–Pacific region including around New Zealand, Japan and Australia (Kailola *et al.* 1993). In Australia, *P. auratus* has a continuous distribution around the southern coastline of mainland Australia, from Gladstone in Queensland to Barrow Island in Western Australia, inhabiting the coastal marine waters from the shallows out to 200 m depth (Kailola *et al.* 1993).

While juvenile *P. auratus* are generally found in shallow, nearshore habitats, including marine embayments and estuaries, sub-adults and adults inhabit marine embayments and coastal reefs as well as other habitats over the continental shelf (Kailola *et al.* 1993; Gillanders *et al.* 2003). *Pagrus auratus* display a range of life-stage related movement pattens throughout their geographic range (Johnson *et al.* 1986; Edmonds *et al.* 1999; Coutin *et al.* 2003; Fowler & Jennings 2003; Sumpton *et al.* 2003; Jackson 2007). In coastal waters near Perth (32°S), sub-adults leave juvenile nursery areas in Cockburn and Warnbro Sound (Lenanton 1974) and move offshore to waters up to 200 m in depth. When mature, these fish appear to return to the nursery areas during spring and early summer to spawn in aggregations (Wakefield 2006). Further north, *P. auratus* in oceanic waters off Shark Bay (24°S) migrate to inshore reefs every winter to form spawning aggregations (Moran *et al.* 2003).

Pagrus auratus support important commercial and recreational fisheries in most mainland states of Australia. The national annual commercial catch (~1,600 tonnes in 2004) is now considerably lower than the peak of ~2,500 tonnes per year recorded in the early 1980s (Kailola *et al.* 1993). The National Recreational Fishing survey in 2000–01 estimated that ~1,400 tonnes of pink snapper was taken by recreational fishers in the survey period, with the species ranked fourth (by weight) of all species caught (Henry & Lyle 2003).

2.2 Description of the fishery

For fishery management purposes, the Western Australian Department of Fisheries divides its marine jurisdiction into four bioregions. The West Coast Bioregion (WCB) extends from Kalbarri (27°00'S) to Augusta (115°30'E) (Fig. 2.1).

The West Coast Demersal Scalefish Fishery (WCDSF) encompasses much of the line fishing for demersal scalefish species undertaken by commercial, charter and recreational vessels within the WCB, but excluding demersal longline and net fishing. Up to date details of the commercial, charter and recreational sectors of the fishery and the management arrangements (current, being implemented or proposed) can be found in Fisheries Management Papers 224, 225, 228 and 231 (Anon 2007a; Anon 2007b; Anon 2008a; Anon 2008b).

2.3 Study sites

The WCB was divided into three regions for the purposes of this study i.e. North, Metro, and South (Fig. 2.1). The Kalbarri and Mid-west management zones were combined within a North region. The demarcation of these regions, or zones, within the WCB was based on historical and contemporary patterns of fishing as discerned from catch records and an understanding of the fleet behaviours of the different sectors. The chosen "resolution" of demarcation, whereby there were only three main regions, was a pragmatic decision that reflected the likelihood of the research obtaining sufficient data from each region.

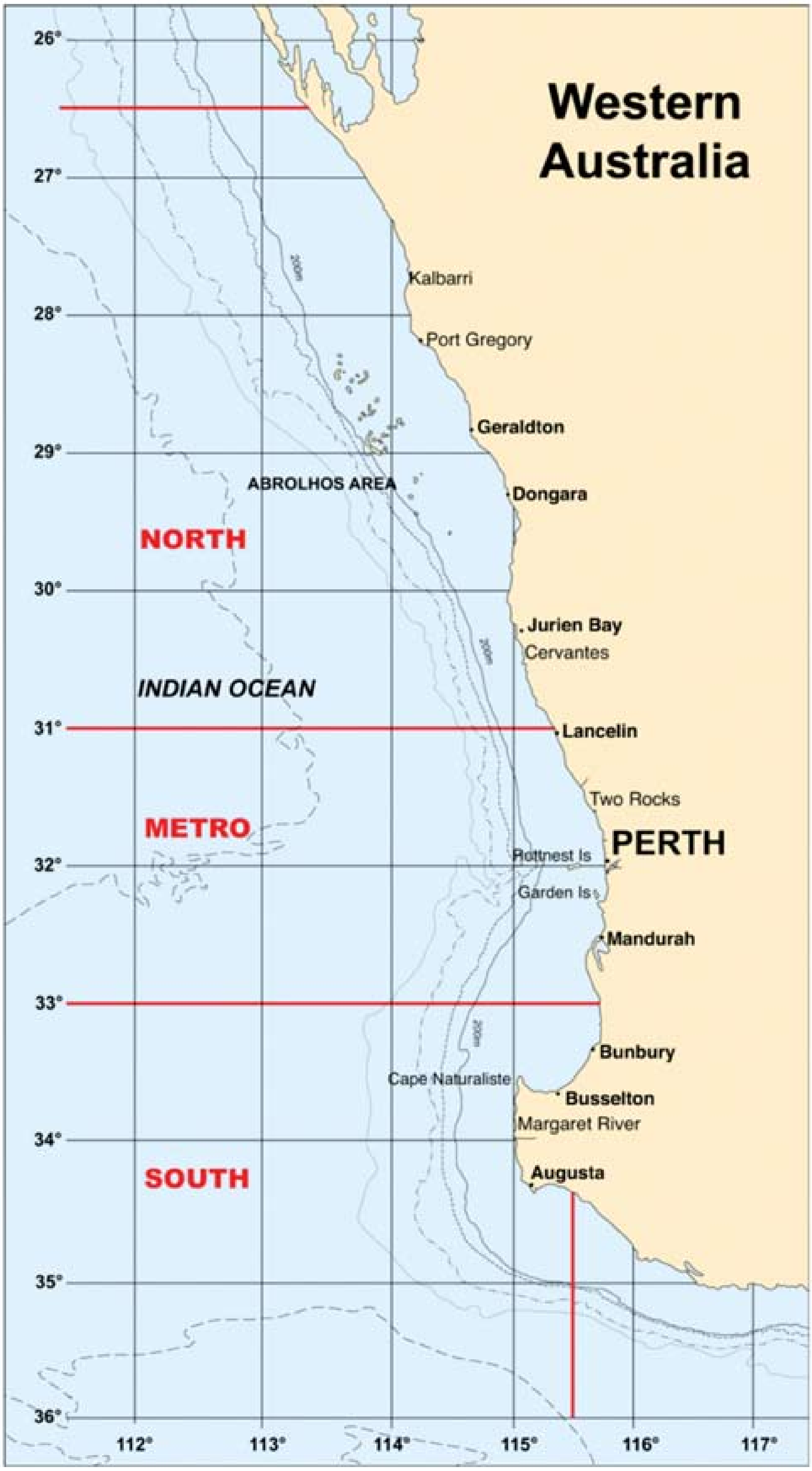

Figure 2.1. Main fishing locations and sampling regions for *Glaucosoma hebraicum* and *Pagrus auratus* within the West Coast Bioregion, and the North, Metropolitan and South regions used in this study.

2.4 Sample collection and processing

2.4.1 Sample collection

Samples of both *G. hebraicum* and *P. auratus* were collected between October 2002 and December 2005 from a range of locations between north of Kalbarri (~ 26°S) and Cape Leeuwin (~34.5°S) (Fig. 2.1). Due to difficulties in obtaining adequate numbers of *G. hebraicum*, sampling was continued through to June 2006.

Commercial catches of *G. hebraicum* and *P. auratus* taken by a range of gear types (handline, dropline, longline, demersal gill net) were sampled by obtaining the filleted frames of legal size fish from processing factories and from local restaurants. Recreationally caught fish were sampled as either whole fish or frames directly from individual fishers or collected via weigh-ins at local fishing competitions. Undersize fish (< legal size) were obtained by Department of Fisheries research staff and limited numbers of recreational and commercial fishers fishing with exemptions to retain undersized fish. While most samples were obtained via fishery-dependent sampling, efforts were made to ensure that sampling biases were minimised where possible. Sample numbers of *G. hebraicum* and *P. auratus* collected from various sectors (including research samples) are shown below.

Table 2.1. Number of *Glaucosoma hebraicum* obtained from each sector in each of the three regions in 2002, 2003, 2004, 2005 and 2006. [This is the same as Table 5.3]

Region	Sector	Year					%
		2002	2003	2004	2005	2006	
North	Commercial	91	769	285	236	22	84
	Recreational						
	Fishing club			38		44	5
	Other		2	3	74	1	5
	Research	8	32	4	54		6
	Total	**99**	**803**	**330**	**364**	**67**	**1663**
Metropolitan	Commercial	33	51	33	42		14
	Recreational						
	Fishing club		14	140	213	49	38
	Fishing charter		7	22	17	2	4
	Other	1	25	190	150	68	39
	Research	2	7	25	2	7	4
	Total	**36**	**104**	**410**	**424**	**126**	**1100**
South	Commercial		48	61	85	81	34
	Recreational						
	Fishing club		32	53	121	112	39
	Other	24	19	64	74	26	25
	Research			1	12		2
	Total	**24**	**99**	**179**	**292**	**219**	**813**
Grand total		**159**	**1006**	**919**	**1080**	**412**	**3576**

Table 2.2. Number of *Pagrus auratus* collected by sampling region, sector and year. [This is the same as Table 7.2].

Region	Sector	Year				%
		2002	2003	2004	2005	
North	Commercial	5	680	519	579	91
	Recreational	1	3		68	4
	Research		69		35	5
	Total	**6**	**752**	**519**	**682**	**1959**
Metropolitan	Commercial	444	297	29		44
	Recreational					
	Fishing club		23	93	125	14
	Fishing charter			303	23	19
	Other	4	42	48	49	8
	Research	12	85	115	57	15
	Total	**460**	**447**	**588**	**254**	**1749**
South	Commercial			106	64	45
	Recreational	10	16	26	104	41
	Research		32		24	15
	Total	10	48	132	192	382
Grand total		**476**	**1247**	**1239**	**1128**	**4090**

2.4.2 Sample processing

All fish were measured (for *P. auratus* total length TL and fork length FL, for *G. hebraicum*, total length TL only) to the nearest 1 mm and when possible weighed (total wet weight) to the nearest 0.1 g.

For both species, both sagittal otoliths were extracted, cleaned, dried and stored in paper envelopes. Note that with approximately 30% of the commercially caught *P. auratus* the otoliths were damaged due to the widespread use of the technique of brain-spiking ('iki jimi').

For both species, the paired gonads were dissected from the fish, examined macroscopically, sexed and weighed to the nearest 0.01 g. For *G. hebraicum* only, samples of fresh gonads (both sexes) each month were fixed in 10% formalin and seawater solution for subsequent histological analysis. In the laboratory, a sub-sample of each ovary approximately 3 mm thick was removed from the central region of the preserved gonad and processed using standard histological techniques to provide 5–7 µm transverse sections that were stained using Harris's haematoxylin and eosin (H&E).

2.4.3 Otolith preparation

For both species, both sagittal otoliths were weighed to the nearest 0.0001 g and measured (total length, posterior to anti-rostrum length and width at core) to the nearest 0.01 mm. One randomly selected otolith from each fish was embedded in clear polyester resin and transversely sectioned (250–300 µm thick) using a Buehler-Isomet low-speed saw. For *P. auratus*, one section, that included the primordium, was cut from each otolith. For *G. hebraicum*, three sections were cut from each otolith initially to ensure that the primordium would be examined. Once the technique had been developed, two sections only were cut from the *G. hebraicum* otoliths. All sections were cleaned and mounted in a casting resin on microscope slides under cover slips.

3.0 Level of intermixing among populations

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Objective 1 Examine the level of intermixing among populations of both P. auratus and G. hebraicum along the West Coast to determine the appropriate geographical scales for management

3.1 Introduction

Distributions of marine species exist at different spatial scales and are defined by the level of the interaction among their members. The definitions of scale used here follow Hanski and Gilpin (1997) and from smallest to largest are:

- At the *local* scale, individuals interact with each other during the normal course of feeding and breeding (living); an individual belongs to one local population for most of its life. Note that for many species that the "local" scale can nonetheless be very extensive.
- A *metapopulation* is a set or constellation of local populations that are linked by dispersal.
- The *geographic range* of a species encompasses all local populations and metapopulations within it; an individual typically does not move over much of its geographic range during the course of its lifetime.

In fisheries, local populations are referred to as stocks and identification of stocks is very important to management of the fishery because both population parameters and dynamics can vary among adjacent stocks. It is important to understand the level of intermixing and exchange of individuals between stocks to determine the scale of management required in the fishery. Management actions must be based on knowledge of the biological attributes and rates of exploitation of each stock. Failure to identify separate stocks can lead to overfishing and, eventually, stock depletion, for which there are many examples worldwide (*e.g.* Myers *et al.* 1997).

While studying genetics (protein variation, mitochondrial DNA and nuclear DNA, Begg & Waldman 1999) is useful for discrimination of broad-scale fish distributions that are geographically isolated, genetics cannot easily distinguish between local or meta-populations that have some (low) level of inter-mixing. Thus, techniques of analysing chemical compositions of calcified structures, which act as environmental recorders (Campana 1999), have been developed to discern low levels of mixing between stocks. The most commonly used calcified structure, the otolith, is composed predominantly of calcium carbonate with some trace elements that are incorporated from their habitat. The chemical signature of otoliths from fish from different geographical locations can be determined for either the entire lifetime of the fish using the whole otolith, or for specific ontogeny using parts of the otolith reflecting that age (Campana 1999). Differences in the abundance of stable isotopes of carbon and oxygen in otolith carbonates between stocks are measured using isotope ratio mass spectrometry (IRMS), while differences in the composition of trace elements are measured using inductively coupled plasma mass spectrometry (ICPMS) techniques (see review by Campana 1999).

Differences in the signatures of stable isotopes of oxygen and carbon in otolith carbonates have been used to delineate stocks without detailed knowledge of the underlying chemical processes leading to these differences, since the differences alone imply stock separateness (Edmonds & Fletcher 1997; Edmonds *et al.* 1999; Stephenson *et al.* 2001; Bastow *et al.* 2002).

Oxygen isotopes in otolith carbonate are deposited in equilibrium, or close to equilibrium, with ambient seawater (Devereux 1967; Kalish 1991a; Patterson *et al.* 1993; Radtke *et al.* 1996; Thorrold *et al.* 1997). Assuming that the isotopic composition of the seawater throughout the study region is constant, then water temperature is the principal factor determining isotopic fractionation, and moreover this effect is predictable (Kalish 1991a).

When the isotopic composition of the seawater is not uniform, for example in regions of variable salinity, although the oxygen isotopes will be deposited in the otolith in equilibrium with the seawater in that region, the equilibrium isotopic composition will differ depending on the salinity of the seawater. For example, Bastow *et al*. (2002) showed that a strong positive correlation existed between increasing seawater salinity and increasing enrichment in ^{18}O in otoliths from pink snapper in Shark Bay, Western Australia, and that at constant temperature, this effect is predictable.

In contrast, deposition of carbon into the otoliths is not regulated solely by thermodynamics. Metabolic rates and diet, both of which can vary with age (Kalish 1991b; Thorrold *et al.* 1997), also affect the isotopic composition in the carbonate and the carbon isotopes are therefore deposited in non-equilibrium with the seawater.

In Western Australia, stable isotope analyses of carbon and oxygen in otolith carbonate has been used successfully to delineate stocks of pink snapper (*Pagrus auratus*), tailor (*Pomatomus salatrix*) and grass emperor (*Lethrinus laticaudis*) in Shark Bay (Edmonds *et al.* 1999; Bastow *et al.* 2002; Ayvazian *et al.* 2004a) and have contributed to an understanding of the spatial dynamics of pilchard (*Sardinops sagax*) in south-west Australia (Edmonds & Fletcher 1997; Gaughan *et al.* 2002).

Of the two species investigated in this report, stock structure and/or movement of *P. auratus* have been studied using otolith microchemistry in WA and elsewhere in Australia including New South Wales (Gillanders 2002; Gillanders & Kingsford 2003), Victoria (Hamer *et al*. 2003; Hamer *et al.* 2005) and South Australia (Fowler *et al.* 2005). Stable isotopes of *G. hebraicum* otoliths have previously been examined in a limited manner by Bastow (unpublished data, Department of Fisheries, Western Australia).

3.1.1 Pilot study

Prior to this project, we ran a pilot study to ensure that there were detectable differences in stable isotopes in otoliths of *G. hebraicum* from different locations within the west coast, and to examine causes of variability in $\delta^{13}C$ and $\delta^{18}O$[1]. The results of this pilot study are not included in this chapter because most of the specimens examined in the pilot study were not of a comparable size range to those chosen for the main study. Likewise, $\delta^{13}C$ and $\delta^{18}O$ values reported by Edmonds *et al.* (1999) for *P. auratus* from Cockburn Sound (Metropolitan region) and Abrolhos Islands (North region) were not compared to results obtained in the present study for the same reasons.

The pilot study concluded that when the size-range is restricted, stable isotope ratios differ sufficiently to show that individual *G. hebraicum* within populations located within waters off approximately 400 km of coastline do not intermix. Four sources of variability were examined in the pilot study, including two temporal scales – within seasons (4 months) and between seasons (six months), spatial scales (several km) and fish size. Of the four sources of variability examined, sampling within seasons (4 months) and within regions (several km) did not increase variability in the stable isotopes. Between seasons, however, increased variability in both $\delta^{18}O$ and $\delta^{13}C$ and the increased size of fish increased variability of $\delta^{18}O$. Based on the results of the pilot study, the sampling design for *G. hebraicum* used a restricted size range of fish specimens, sampled during the same season of the year. Similarly, Bastow *et al.* (2002) used a restricted size range of fish for their statistical comparison of *P. auratus* in Shark Bay.

3.2 Methods

3.2.1 Dhufish

The pilot study on *G. hebraicum* otolith chemistry found that the signature of $\delta^{18}O$ was affected by the weight of the otolith. Due to the wide size range and the longevity of *Glaucosoma hebraicum,* a restricted size range of *G. hebraicum* (601 – 696 TL) was sub-sampled from handline catches during October to December 2004 for each of the three regions (Table 3.1, Fig. 3.1). A total of 63 *G. hebraicum* were collected from several locations in three regions (Table 3.1).

3.2.2 Pink snapper

For each region a restricted size range (413 – 502 mm TL) of *P. auratus* was sub-sampled from samples caught by handline during October and November 2004 (Table 3.2, Fig. 3.1). A total of 76 specimens of *P. auratus* were sub-sampled from six locations in three regions. One location, Port Gregory was sampled in the North, three locations were sampled in the Metropolitan region, namely Two Rocks, Ocean Reef and Offshore, and two locations, Bunbury and Cape Naturaliste, were sampled in the South (Table 3.2).

3.2.3 Preparation of the otoliths for IRMS analysis

Both sagittal otoliths were extracted from the fish as soon as possible after capture, washed with distilled water, patted dry and placed in a paper envelope for storage (see Section 2.5 for collection and processing of samples). The otolith was later washed in deionised water then dried. The dried otolith was ground to a fine powder using a mortar and pestle. Protein was extracted from the powder by treatment with two successive 3 ml portions of 5 % sodium hypochlorite solution. Each portion remained in contact with the otolith powder for 2 hours, with an initial 30-minute period of ultrasonically assisted extraction. Residual sodium hypochlorite was removed by rinsing the powder with deionised water (4 x 3 ml). Following each rinse, the mixture was centrifuged (approx. 3000 rpm for 5 min.) and the supernatant aqueous layer was removed using a Pasteur pipette. The powder was oven-dried at approximately 105 °C for a minimum of 24 hours, and then allowed to cool in a desiccator.

A sub sample of the extracted carbonate powder (typically 10 mg) was sealed in a polypropylene micro test tube, and stored in a desiccator until dispatch to the laboratory (Isoanalytical Ltd., UK) for analysis. Samples of two standard reference materials (URM and RM) consisting of pooled otoliths extracted from red emperor (*Lutjanus sebae*) and ground to a fine powder, were treated in an identical manner to the ground otolith material from the *G. hebraicum* and *P. auratus* samples.

3.2.4 Stable isotope analysis

Prior to analysis, the samples and standard reference materials were dried in an oven at 60°C for a period of at least 24 hours to remove any residual water that may interfere with the determination of $\delta^{18}O$. Approximately 2 mg of the dried powder was placed into a clean glass septum-capped vial. The vial was sealed and the headspace flushed with pure helium

(99.995 %). After flushing, purified phosphoric acid (*ca* 0.5 ml) was injected into the vials, mixed with the sample powder and the mixture was allowed to react overnight. The carbon dioxide gas generated by treatment of the carbonate with phosphoric acid was introduced into a Europa Scientific 20-20 continuous flow isotope ratio mass spectrometry (IRMS). Standard reference materials (0.5 mg) in addition to RM and URM were prepared in the same manner as the samples to correct for the temperature dependent fractionation of carbonate during the conversion to carbon dioxide (CO_2).

The instrument was calibrated prior to analysis of the otolith sub samples by determination and comparison with the known $\delta^{13}C$ and $\delta^{18}O$ values of each of two secondary isotopic reference standards, namely *NBS-18 Calcite* and *NBS-19 Limestone*, both distributed by the International Atomic Energy Agency, Vienna. During the analysis, samples of these two standards as well as the calcium carbonate standard *IA-R022*, which is traceable to *NBS-19 Limestone*, and *RM* and *URM* were interspersed amongst the otolith sub samples to verify the performance of the IRMS. Results are reported in standard delta (δ) notation relative to the PDB-1 standard.

3.2.5 Environmental variables and proxy temperature history

Measures of salinity and temperature in the West Coast Bioregion (WCB) are described in Section 5.2.4. The temperature history of each fish was inferred using the age and location of capture. A single temperature value for each fish was calculated by averaging the annual mean SST for each year since birth, including 2005 as fish were sampled late in that year (October to December), for the specific location of capture.

3.2.6 Statistical analysis

The results of the IRMS analysis ($\delta^{13}C$ and $\delta^{18}O$) for each region were tested separately using an Analysis of Variance (ANOVA) comparing regions, age of fish and environmental variables.

3.3 Results

3.3.1 Salinity and temperature

Annual averages of salinity at ocean surface and bottom are similar and range from 35.3 to 36.5 ‰. Inter-annual variability in salinity is much higher than spatial variability throughout the regions sampled on the west coast or variability with depth. There appears to be no consistent salinity gradient along the WCB, although gradients and partial gradients may occur in surface waters in some years. Therefore, salinity should not influence the analysis and interpretation of the spatial patterns in otolith microchemistry of fishes along the lower west coast. Conversely, water temperature varied significantly with latitude (Figs 4.1 & 6.2), and hence would influence the interpretation of $\delta^{18}O$ isotope ratios.

3.3.2 Dhufish

Despite a restricted size range of fish, the average age of *G. hebraicum* was one year younger in the Metropolitan region compared to the other two regions (Table 3.1), however the average weight of otoliths was similar between regions (Table 3.1).

Individual values of $\delta^{13}C$ ranged from -4.86 to -2.74 with a mean of -4.06 and values of $\delta^{18}O$ ranged from -0.110 to 0.921 with a mean of 0.353.

$\delta^{13}C$ in otoliths varied significantly among regions (p = 0.0018) (Fig. 3.2). $\delta^{18}O$ in *G. hebraicum* otoliths varied significantly among all regions (p = 0. 0000), but while the North region differed from the other two regions, the Metropolitan and South regions did not differ significantly (Fig. 3.2). Sea surface temperatures explained patterns of $\delta^{18}O$ in *G. hebraicum* otoliths as the latitudinal increase in sea water temperature was reflected by decreasing values of $\delta^{18}O$ (*i.e.* depletion of $\delta^{18}O$) in the otoliths (Fig. 3.3).

3.3.3 Pink snapper

Despite the restricted size range, the average total length, age and otolith weight of *P. auratus* varied among regions, which most likely represents regional differences in growth (see Section 7.0). On average, the length, age and weight of otoliths of *P. auratus* were slightly higher in the North region (Table 3.2 and Fig. 3.1). The age of *P. auratus* ranged from 4-9 years in the South region, 3-5 years in the Metropolitan region and 4-8 years in the North region (Table 3.2).

$\delta^{13}C$ in otoliths from the South region varied from the other two regions (p = 0.0064), which had very similar $\delta^{13}C$ values (Fig. 3.2).

$\delta^{18}O$ values varied significantly among regions (p = 0. 0158); the North region differed from the Metropolitan region (p = 0.0042) but not from the South region (p = 0.0926, Fig. 3.2). No trend was obvious between $\delta^{18}O$ values and sea surface temperatures (Fig. 3.3).

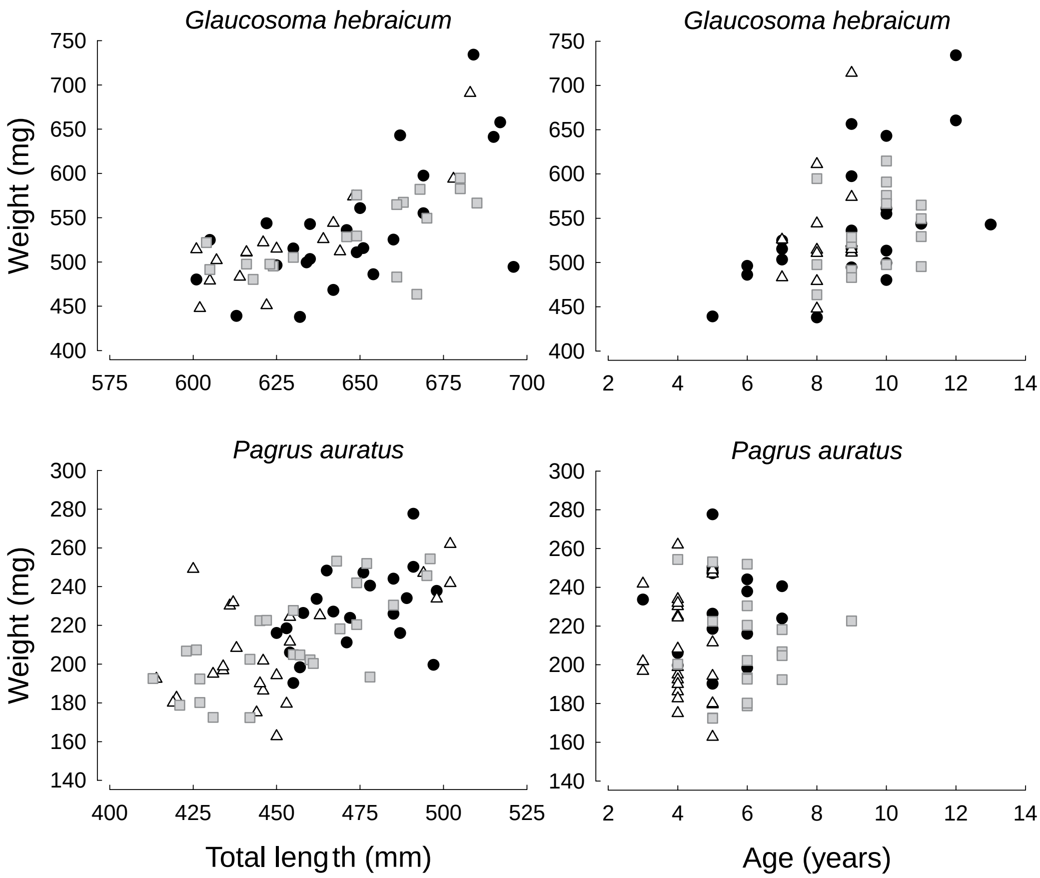

Figure 3.1. Comparisons of total lengths (left) and ages (right) with weight of otoliths of *Glaucosoma hebraicum* (above) and *Pagrus auratus* (below) caught in the North (black circles), Metropolitan (white triangles) and South (grey squares) regions (see Tables 3.1 & 3.2 for sample sizes).

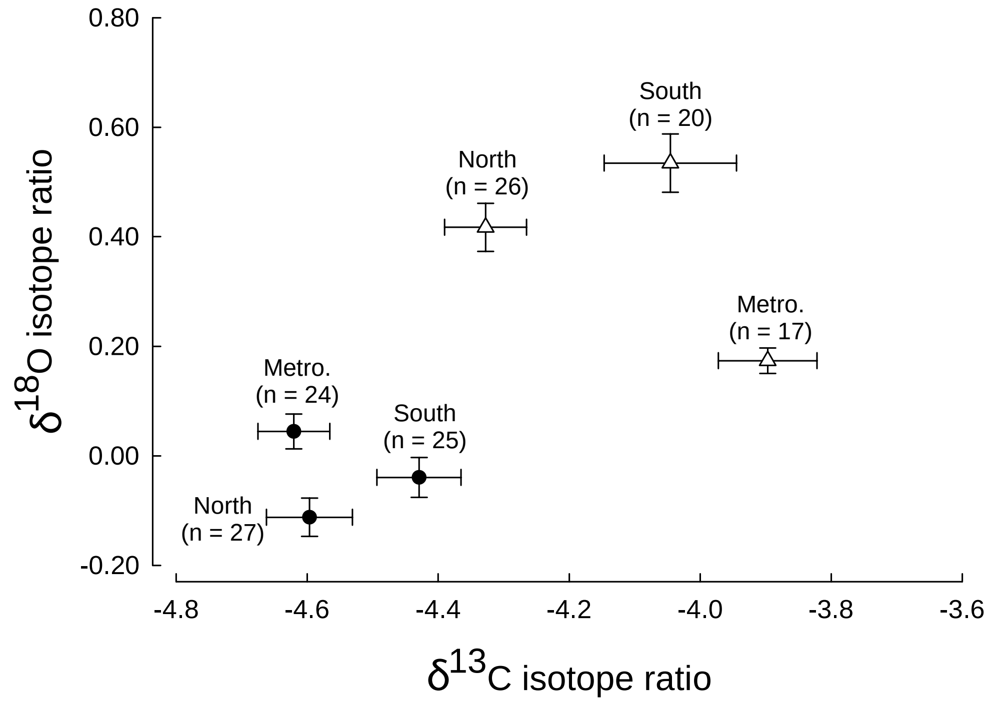

Figure 3.2. Mean (± 1 SE) $\delta^{18}O$ and $\delta^{13}C$ for *Glaucosoma hebraicum* (triangles) and *Pagrus auratus* (circles) caught in October to December in 2004 from the North, Metropolitan and South regions (sample sizes shown).

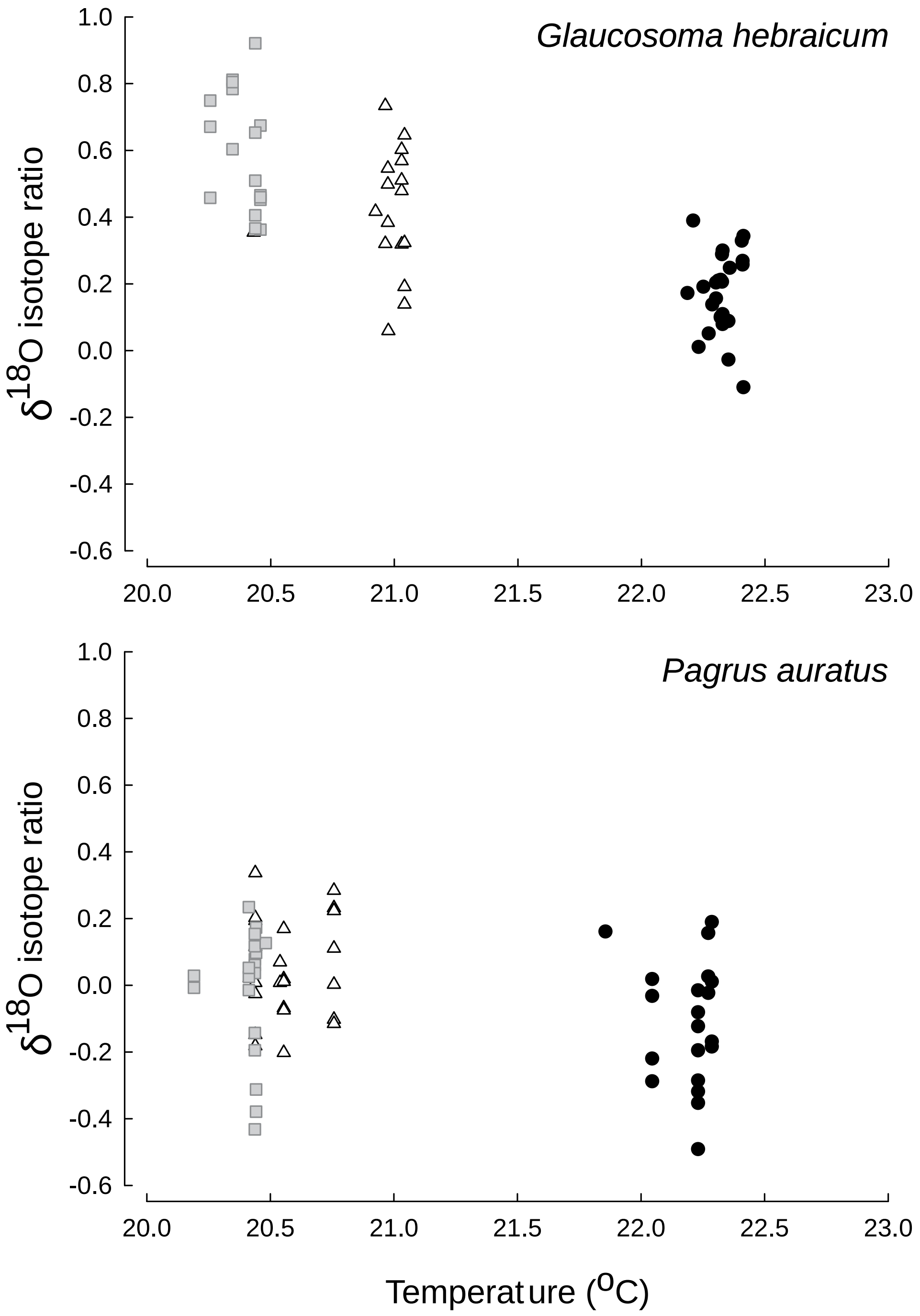

Figure 3.3. $\delta^{18}O$ in otoliths of *Glaucosoma hebraicum* (above) and *Pagrus auratus* (below) compared to temperature history of each fish using surface seawater temperatures in the North (black circles), Metropolitan (white triangles) and South (grey squares) regions (see Tables 3.1 & 3.2 for sample sizes).

Table 3.1. Summary of the total lengths, age and otolith characteristics of *Glaucosoma hebraicum* caught between October and December 2004 in each location within the North, Metropolitan and South regions.

Location	TL (mm)		Age (years)		Otolith weight (mg)		δ13C		δ18O	
	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)
North region										
All locations	648 (± 28.7)	601-696 (26)	9.3 (± 2.7)	5-18 (25)	539 (± 74.3)	438-734 (23)	-3.90 (± 0.38)	-4.86 to -3.25 (26)	0.17 (± 0.12)	-0.11 to 0.39 (26)
Port Gregory	632 (± 20.6)	613-654 (3)	6.0 (± 1.0)	5-7 (3)	480 (± 38.4)	439-515 (3)	-4.38 (± 0.50)	-4.86 to -3.86 (3)	0.07 (± 0.07)	0.01 to 0.14 (3)
Abrohlos Is.	658 (± 28.9)	605-695 (12)	9.8 (± 3.3)	6-18 (11)	571 (± 87.5)	468-734 (10)	-3.89 (± 0.34)	-4.47 to -3.42 (12)	0.20 (± 0.15)	-0.11 to 0.39 (12)
Geraldton	641 (± 28.3)	601-696 (11)	9.7 (± 1.4)	8-13 (11)	525 (± 54.7)	438-643 (10)	-3.78 (± 0.33)	-4.39 to -3.25 (11)	0.18 (± 0.08)	-0.08 to 0.30 (11)
Metropolitan region										
All locations	631 (± 25.9)	601-683 (17)	8.3 (± 0.7)	7-9 (16)	531 (± 63.5)	448-714 (15)	-4.33 (± 0.26)	-4.83 to -4.05 (17)	0.42 (± 0.18)	0.06 to 0.73 (17)
Lancelin		648 (1)		9 (1)		574 (1)		-4.60 (1)		0.65 (1)
Two Rocks	638 (± 27.2)	602-678 (7)	8.0 (± 0.6)	7-9 (7)	528 (± 58.8)	448-611 (5)	-4.42 (± 0.32)	-4.83 to -4.05 (7)	0.41 (± 0.19)	0.06 to 0.60 (7)
Ocean Reef	654 (± 41.0)	625-683 (2)	9.0 (± 0)	9 (2)	615 (± 140.7)	515-714 (2)	-4.34 (± 0.33)	-4.57 to -4.10 (2)	0.17 (± 0.04)	0.14 to 0.19 (2)
Rottnest Is.	610 (± 6.4)	605-614 (2)	7.5 (± 0.7)	7-8 (2)	481 (± 2.8)	479-483 (2)	-4.18 (± 0.07)	-4.23 to -4.14 (2)	0.46 (± 0.06)	0.42 to 0.50 (2)
Garden Is.	618 (± 19.1)	601-644 (4)	8.7 (± 0.6)	8-9 (3)	531 (± 8.2)	502-522 (4)	-4.14 (± 0.06)	-4.20 to -4.07 (4)	0.49 (± 0.19)	0.32 to 0.73 (4)
Mandurah		616 (1)		8 (1)		511 (1)		-4.40 (1)		0.38 (1)
South region										
All locations	647 (± 25.6)	604-685 (20)	9.6 (± 1.1)	8-11 (17)	536 (± 44.2)	464-734 (18)	-4.05 (± 0.45)	-4.61 to -2.74 (20)	0.53 (± 0.24)	-0.11 to 0.92 (20)
Bunbury	641 (± 29.2)	605-685 (8)	10.1 (± 0.8)	9-11 (8)	535 (± 38.2)	491-576 (7)	-3.98 (± 0.27)	-4.36 to -3.52 (8)	0.61 (± 0.15)	0.41 to 0.80 (8)
Busselton		668 (1)		10 (1)		591 (1)		-2.74 (1)		0.92 (1)
Geographe Bay	652 (± 13.4)	642-661 (2)		9 (1)		483 (1)	-3.96 (± 0.03)	-3.98 to -3.94 (2)	0.44 (± 0.01)	0.43 to 0.45 (2)
C. Naturaliste	645 (± 26.3)	604-680 (6)	9.8 (± 1.0)	9-11 (4)	544 (± 40.1)	505-615 (6)	-4.20 (± 0.45)	-4.61 to -3.32 (6)	0.34 (± 0.31)	-0.11 to 0.81 (6)
Cowaramup		667 (1)		8 (1)		464 (1)		-4.58 (1)		0.46 (1)
Hamelin	652 (± 40.3)	623-680 (2)	8.0 (± 0)	8 (2)	547 (± 68.6)	498-595 (2)	-4.33 (± 0.04)	-4.35 to -4.30 (2)	0.71 (± 0.06)	0.67 to 0.75 (2)

Table 3.2. Summary of the total lengths, age and otolith characteristics of *Pagrus auratus* caught between October and December 2004 in each location within the North, Metropolitan and South regions.

Location	TL (mm)		Age (years)		Otolith weight (mg)		δ13C		δ18O	
	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)	μ (± 1 SD)	range (n)
North region										
Port Gregory	461 (± 34.9)	372-498 (27)	6.2 (± 1.1)	4-8 (20)	227 (± 20.8)	190-278 (21)	-4.60 (± 0.34)	-5.44 to -3.94 (27)	-0.11 (± 0.18)	-0.49 to 0.24 (27)
Metropolitan region										
All locations	447 (± 26.5)	407-502 (24)	4.2 (± 0.6)	3-5 (24)	208 (± 26.9)	163-262 (24)	-4.62 (± 0.27)	-5.21 to -4.11 (24)	0.05 (± 0.15)	-0.20 to 0.34 (24)
Two Rocks	457 (± 33.5)	419-502 (7)	4.4 (± 0.8)	3-5 (7)	214 (± 35.8)	179-262 (7)	-4.57 (± 0.31)	-4.87 to -4.11 (7)	0.08 (± 0.15)	-0.10 to 0.28 (7)
Ocean Reef	451 (± 20.3)	431-494 (8)	4.3 (± 0.7)	3-5 (9)	204 (± 25.4)	163-247 (8)	-4.72 (± 0.34)	-5.21 to -4.11 (8)	0.01 (± 0.13)	-0.20 to 0.22 (8)
Offshore	436 (± 24.1)	407-490 (9)	3.9 (± 0.3)	3-4 (9)	208 (± 22.6)	175-234 (9)	-4.58 (± 0.14)	-4.80 to -4.34 (9)	0.06 (± 0.17)	-0.18 to 0.34 (9)
South region										
All locations	453 (± 24.0)	413-496 (25)	5.9 (± 1.2)	4-9 (19)	212 (± 24.9)	172-254 (25)	-4.43 (± 0.33)	-5.06 to -3.80 (25)	-0.04 (± 0.19)	-0.43 to 0.23 (25)
Bunbury	454 (± 23.9)	413-496 (22)	6.0 (± 1.3)	4-9 (16)	214 (± 23.7)	173-254 (22)	-4.38 (± 0.31)	-5.06 to -3.80 (22)	-0.05 (± 0.17)	-0.20 to 0.17 (22)
C. Naturaliste	451 (± 30.1)	427-485 (3)	5.7 (± 0.6)	5-6 (3)	194 (± 31.4)	172-230 (3)	-4.81 (± 0.07)	-4.89 to -4.75 (3)	-0.01 (± 0.36)	-0.43 to 0.23 (3)

Note Offshore location in Metropolitan region refers to waters deeper than 80 m.

3.4 Discussion

3.4.1 Dhufish

Seawater temperatures increased with decreasing latitude (i.e. south to north) within the West Coast Bioregion. When fish populations do not intermix this latitudinal gradient in sea temperature is expected to be evident in $\delta^{18}O$ values in otolith carbonate because ^{18}O is depleted with increasing water temperature. Conversely, if populations of fish intermix among the three regions in the West Coast Bioregion, then the $\delta^{18}O$ signature would be more similar among regions.

The trend in $\delta^{18}O$ signatures for *G. hebraicum* reflected the increase in water temperatures from south to north, with otolith carbonate from fish in the cooler waters in the South being most enriched in ^{18}O. $\delta^{18}O$ values delineated *G. hebraicum* in the North from those in the Metropolitan and South regions, indicating some degree of geographic residency within the regions of the West Coast Bioregion. Although dhufish from the South and Metropolitan regions were not delineated by $\delta^{18}O$, the lack of a significant difference between these two southern regions may be due to their closer proximity and the resultant small difference in temperature history (see Fig. 3.3). Thus, given the latitudinal temperature gradient, the $\delta^{18}O$ values likely form a latitudinal continuum, with distant samples being more likely to be different (and visa versa) if fish do not mix extensively throughout the bioregion. Furthermore, $\delta^{13}C$ also varied between all regions for dhufish. Although variations in $\delta^{13}C$ in many fish species can reflect ontogenetic changes in metabolism and/or diet, the minimal regional differences in mean fish size and otolith weight for dhufish suggest that ontogeny was not responsible for the different $\delta^{13}C$ signatures. The results for the analyses of $\delta^{18}O$ and $\delta^{13}C$ are sufficient to conclude that mixing of post-settlement dhufish throughout the West Coast Bioregion is limited.

Although current knowledge of the behaviour and physiology of adult *G. hebraicum* provide no indication that juveniles would actively swim along the coastline, such dispersal cannot be completely ruled out. Juvenile dhufish are known to inhabit low-relief reef (*i.e.* hard bottom) and to maintain this association may not move large distances, or at least may be restricted by the extent and continuity of suitable habitat to which they first settle. If this is the case, dispersal of the eggs and larvae is the only method that progeny of *G. hebraicum* can mix widely along the WCB. If egg and larval dispersal is localised, then populations of *G. hebraicum* could be locally self-sustaining but could then also be vulnerable to localized depletion. In contrast, if eggs and larvae are more widely dispersed to other geographical locations, then areas with localised depletion can be replenished by healthier populations from elsewhere. The importance of local and broad-scale recruitment could vary from year to year in *G. hebraicum* depending on local reproductive output and oceanographic conditions. Clarification of the spatial dynamics of dhufish requires further research, some of which has already begun.

3.4.2 Pink Snapper

The trends in $\delta^{18}O$ signatures of the otolith carbonate of *P. auratus* contrasts with the regional gradient observed for *G. hebraicum*, with no relationship to the latitudinal gradient in temperature. As expected, the lowest mean $\delta^{18}O$ occurred in the North region (highest temperature) but this was not significantly different from the South region. Neither did the $\delta^{18}O$ signature for the Metropolitan region differ to that for the South region. These results are more difficult to interpret than those for dhufish because the inshore waters where pink snapper spawn and reside as small juveniles are (a) more variable in terms of temperature and salinity, both of which affect $\delta^{18}O$ signatures, (b) the available temperature histories apply more to oceanic waters than nearshore coastal waters, and (c) the majority of the fish sampled were immature, and thus had insufficient time to develop ‘local’ signatures expected from mature fish. Similarly, the difference in $\delta^{13}C$ between the Metropolitan and South regions suggests a degree of separation for these pink snapper. However but this may reflect the different ages of the fish sampled (4.2 years *vs*. 5.9 years respectively), and does not therefore provide unequivocal evidence for stock structure.

The analyses of oxygen and carbon stable isotopes do not provide any clear evidence that juvenile/immature pink snapper (*i.e*. those < 450 mm TL) reside in particular geographic areas once they have left their nursery area. As discussed below, we suggest that juvenile/immature pink snapper likely mix widely within the WCB.

The spatial dynamics of *P. auratus* in the West Coast Bioregion is very different to that in Shark Bay where very localised populations exist (Bastow *et al.* 2002). *Pagrus auratus* in the West Coast Bioregion may behave similarly to the stock in South Australia in Australia for which Fowler *et al*. (2005) showed that in years of high recruitment, juvenile *P. auratus* of 3-4 years of age dispersed > 2000 km from one or two nursery areas, after which the majority of adult *P. auratus* became residents of a particular region along the coastline of South Australia for the rest of their life. In Victoria, two pink snapper settlement areas, within and outside of Port Phillip Bay, were identified (0-3 months old, Hamer *et al.* 2003). Similar to the situation in South Australia, Victorian pink snapper were believed to have migrated several hundred kilometres, but the geographic origins of *P. auratus* in Victorian waters varied among cohorts. Thus, in these waters, coastal populations of *P. auratus* are comprised of fish originating from the major spawning and nursery area, Port Phillip Bay, as well as from other spawning events and the composition of regional coastal populations varies both temporally and spatially with distance from the spawning/nursery area of Port Phillip Bay (Hamer *et al.* 2005).

If the ontogenic-related movements of *P. auratus* in WA (excepting those in Shark Bay) are similar to other populations around Australia, then it is likely that regional populations in the WCB are comprised of fish originating from major spawning/nursery sites as well as from local spawning events and the contribution of fish from different geographic origins to each cohort will vary both spatially and temporally. It is also likely that after maturity the majority of the population of *P. auratus* will remain within a particular area or region of the coast. Clarification of the spatial dynamics of pink snapper requires further research, some of which has already begun.

4.0 Regional comparisons of the reproductive biology of dhufish *Glaucosoma hebraicum* in the West Coast Bioregion

J. StJohn, I.S. Keay, N.D.C. Jarvis, M.C. Mackie and C. Wakefield

Objective 2 To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction

4.1 Introduction

The West Australian dhufish, *Glaucosoma hebraicum*, are gonochoristic, multiple (serial) spawners with an annual spawning period of approximately six months from late spring to mid-autumn, *i.e.* November to April, with a peak spawning period from December to February (Marr 1980; Abordi 1986; Moy 1986; Hesp *et al.* 2002). The lengths at which 50% of females and males of *G. hebraicum* attain sexual maturity were estimated as 301 and 320 mm total length, respectively, which corresponds to the end of their third year of life for both sexes (Hesp *et al.* 2002).

The size of testes of *G. hebraicum* throughout all maturational stages of development are relatively much smaller than those of ovaries of *G. hebraicum* at similar stages of development. This contrast between the size of testes and ovaries of *G. hebraicum* is especially evident when compared to those of other demersal reef fish species in the temperate waters of Western Australia, *i.e. Pagrus auratus* and *Choerodon rubescens* (Fairclough 2005; Wakefield 2006). The volume of sperm produced by mature testes of *G. hebraicum* is also smaller but particularly denser than that of other marine teleosts, such as *Pagrus auratus* and *Gadus morhua* (Suquet *et al.* 1994; Pironet & Neira 1998). The males of *G. hebraicum* are sexual dimorphic possessing a dorsal fin filament that increases in length exponentially with the length of the fish (Mackie *et al.* 2009). The larger attainable size of males compared to females of *G. hebraicum* (see Section 5.0, Hesp *et al.* 2002), reflects a higher investment of energy into growth rather than reproduction and suggests an individual's size is an important characteristic in their life history strategy (Mackie *et al.* 2009). Circumstantial evidence from video analysis and experiments involving intense fishing at specific localised reefs has displayed unequal sex ratios with more females than males occurring at these locations during the spawning period, *i.e.* one large and occasionally one small male with between two to six females (Mackie *et al.* 2009). In all cases, the largest individual within these groups of *G. hebraicum* were male (Mackie *et al.* 2009). There thus exist some evidence to suggest that the reproductive strategy/behaviour of *G. hebraicum* involves a complex social interaction.

Previous studies of the reproductive biology of *G. hebraicum* included fish from only a portion of the WCB, *i.e.* Mandurah to the Abrolhos Islands. This current study aimed to compare the reproductive biology of this species throughout the WCB. The specific aims of this part of the current study were as follows. 1) Describe and compare the reproductive development of *G. hebraicum* gonads within the North, Metropolitan and South regions of the WCB. 2) Assess the size at maturity of *G. hebraicum*. 3) Determine the batch fecundity of *G. hebraicum*.

4.2 Methods

Details of sample collection and processing are given in Section 2.0.

4.2.1 Annual reproductive cycle

Seasonal patterns in the reproductive activity of *G. hebraicum* were investigated using gonadosomatic indices and the sequential development of male and female gonads.

All gonads were staged macroscopically according to the criteria shown in Tables 4.1 and 4.2. A subset of ovaries were also staged microscopically using histological criteria (Table 4.1) in order to validate the macroscopic stages, confirm the size at maturity, and provide greater detail about the structure and reproductive development of ovaries.

Mean monthly gonadosomatic indices (GSI) for fish with lengths ≥ the estimated length at 50% maturity (L_{50}, Hesp *et al.* 2002) were calculated as follows,

$$GSI = 100 \times [W_g/((W_f - W_g)]$$

where W_g = wet weight of the gonads and W_f = whole wet weight of the fish.

Where fish were not weighed, wet weight was calculated using the relationship between weight and total length for each sex that was derived by Hesp *et al*. (2002),

$$\text{Females } \log W = \log(0.0000417) + 2.859 \log TL$$

$$\text{Males } \log W = \log(0.0000322) + 2.898 \log TL$$

Mean monthly GSIs of female and male *G. hebraicum* ≥ L_{50} at maturity and histological examination of ovaries were used to determine annual trends in reproduction. The timing and duration of the *G. hebraicum* spawning season was compared amongst the three regions.

Table 4.1. Macroscopic and histological stages of development of *G. hebraicum* ovaries.

Stage	Histological stage	Macroscopic
Juvenile	Undifferentiated gonia	Gonad very small, sex of the fish cannot be determined
1 Virgin	Chromatin nucleolus stage (CNS) and Peri-nucleolus stage (PNS) oocytes	Very small gonads Colourless transparent
2 Mature resting	(CNS & PNS). Evidence of prior spawning may include melano-macrophage centres, depleted oocyte numbers and abundant vascular tissue.	Ovaries small and rounded. Usually translucent and pale pink in colour but can be bloodshot and flaccid soon after spawning season.
3 Developing	Cortical alveoli (CA), CNS and PNS oocytes	Ovaries larger than stage 2. Blood capillaries visible. Oocytes may appear partially opaque.
4 Developed	Yolk globule stage (YGS) oocytes.	Ovaries considerably larger and pink to pale orange in colour. Opaque oocytes and blood vessels present.

5a Pre-spawning	Hydrated and/or migratory nucleus stage (MNS) oocytes within lamellae. Old post-ovulatory follicles (POFs) may also be present.	Ovaries rounded and swollen, occupying most of the ventral cavity. Hydrated oocytes visible and may be extruded with pressure. Large blood vessels visible. Ovaries may become bloodshot and flaccid towards end of the spawning season.
5b Spawning / Running ripe	Hydrated oocytes present within the lumen and newly formed POFs within the lamellae. Old POFs may also be presnt	
5c Post-spawn	YGS oocytes and newly formed POFs. (old POFs may also be present).	
6 Spent	> 50 % atresia of YGS oocytes	Ovaries are bloodshot and flaccid.

Table 4.2. Macroscopic stages of development of *G. hebraicum* **testes.**

Stage	Macroscopic
Juvenile	Gonad very small, sex of the fish cannot be determined
1 - Virgin	Very small gonads, ribbon like. Colourless and transparent
2 - Mature resting	Testes flat or wedge shaped, greyish to cream in colour
3 - Developing	Testes larger and whitish in colour
4 - Developed	Testes lobular & white, becoming flaccid and bloodshot towards end of the spawning season. Spermatozoa evident in cut cross-section
5 – Spawning	Sperm extruded with little pressure Large blood vessels visible

4.2.2 Batch fecundity

Macroscopically staged ovaries that contained hydrated oocytes (stage 5) were examined histologically to check that newly formed POFs were absent, thereby confirming that ovulation had not commenced. Preserved ovaries used to estimate batch fecundity were drained, dried and weighed (± 0.1 mg). Tissue samples were taken from the middle region and one-fifth of the distance from each end of one ovary. The oocytes were loosened by gently tapping the piece of ovary with the blunt tip of the forceps, 3–4 drops of glycerin were added, and the sample spread over a petri dish. The number of hydrated oocytes were counted using a dissecting microscope under 10 times magnification. Hydrated oocytes were easily distinguished from other oocytes by their large size, wrinkled appearance compared to other non-hydrated oocytes when preserved in formalin and by their translucency (non-hydrated oocytes are relatively opaque). In the case of damaged hydrated oocytes, only fragments judged to be a major portion of the oocyte were counted. Empty chorions (outer membrane of the hydrated oocyte) were not counted.

Batch fecundity (BF) was calculated as:

$$BF = [E_c/W_s] * W_o$$

Where: E_c = count of hydrated oocytes; W_s = sample weight; and W_o = total weight of both ovaries.

The mean (and SE) batch fecundity was calculated by using counts of hydrated eggs from a minimum of three sections sampled randomly from each gonad. Batch fecundity is the total number of eggs released at one spawning event.

4.3 Results

The gonads of 2,767 *G. hebraicum* were macroscopically staged during this study. Of these 2,308 were weighed and 619 were examined using histological techniques. The latter included 570 ovaries and 49 testes. Overall, the sex ratio of legal-sized fish (> 500 mm TL) was slightly biased towards males. Biological details of fish samples are provided in Table 4.3.

Table 4.3. Details of *Glaucosoma hebraicum* used in examination of reproductive biology.

	North		Metropolitan		South	
Sex	F	M	F	M	F	M
n	726	624	429	478	235	273
Minimum TL (mm)	283	240	257	269	325	376
Maximum TL (mm)	924	1120	997	1104	977	1070
Minimum gonad wt (g)	0.22	0.1	1.2	0.05	1.5	0.1
Maximum gonad wt (g)	420	59	1036	95	653	73
Minimum total wt (g)	585.8	266	800	448.6	642	809.8
Maximum total wt (g)	10680	21825	20400	24000	15500	21200

4.3.1 Gonad morphology

Ovaries ranged in weight from 0.22 to 1035.5 g while testes ranged from 0.05 to 94.86 g. Testes of mature males are small and the GSI low, ranging from 0.007 to 1.2%. In contrast, ovaries may comprise more than 8% of body weight. The heaviest testis weighed only 9% of the heaviest ovary.

Histological evidence confirmed that *G. hebraicum* ovaries are of the asynchronous type, with oocytes of all stages present together within reproductively active ovaries (Plate 4.1, Wallace & Selman 1981). This developmental type, along with the presence of ovaries with both post-ovulatory follicles (POFs) and hydrated or migratory-nucleus stages (MNS) show that female *G. hebraicum* are serial or partial spawners (Plate 4.1, Hunter & Macewicz 1985). Oocytes develop within narrow lamellae, and prior to spawning are ovulated as eggs into the lumen where they are released externally via the gonoduct.

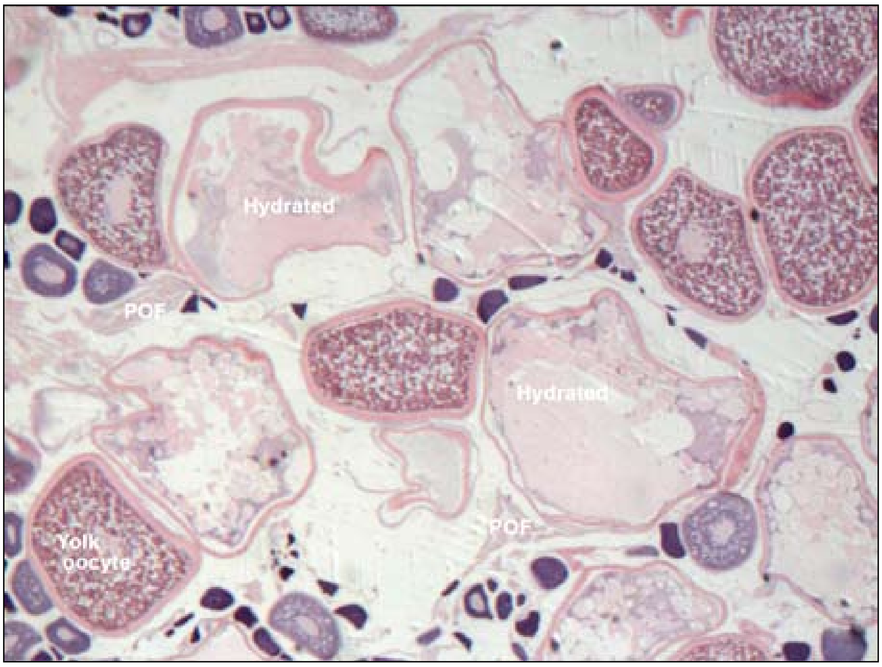

Plate 4.1 Transverse section of an ovary of a spawning (stage 5a) *Glaucosoma hebraicum* showing hydrated and yolk globule stage oocytes alongside and post ovulatory follicles (POF) from a previous spawning event.

4.3.2 Length at maturity

Estimates of the length at sexual maturity based on macroscopic staging of gonads obtained during the spawning season indicated an L_{50} (body length at which 50% of gonads were mature) for *G. hebraicum* females of between 468 and 520 mm TL for the Metropolitan and North regions (data for South region insufficient). This is considerably higher than previous estimates (Hesp *et al.* 2002). However, subsequent assessment of these ovaries using histological techniques indicated that many ovaries classified macroscopically as immature (stage 1) were in fact mature resting (stage 2) or early developing (stage 3). In addition, there were insufficient numbers of immature fish sampled to provide anything but an approximate estimate of L_{50} of around 300 mm TL. This is similar to that estimated by Hesp *et al.* (2002) of 301 mm TL, which was based on larger sample sizes of immature fish and hence was adopted as the length at which 50% of female *G. hebraicum* attain sexual maturity in this study.

The lengths at which male *G. hebraicum* attained sexual maturity were similarly complicated by the small size of the testis and difficulty in producing unambiguous macroscopic and histological criteria for assignment of gonad developmental stages. As for females, the L_{50} for males based on macroscopic assessment was considerably higher than that determined by Hesp *et al.* (2002) of 320 mm TL. This length of 320 mm was subsequently used as the current estimate for male *G. hebraicum* in this study.

4.3.3 Annual and regional trends in reproductive cycles

Trends in GSIs showed that *G. hebraicum* ovaries commence reproductive development in November in all three regions, coinciding with increasing sea surface temperatures (Fig. 4.1). Peaks in the mean monthly GSIs occurred from December to February in the North region, which is a month earlier and longer than the peaks exhibited in the Metropolitan and South regions of January and February. However, actual GSI values of fish in the North region were considerably lower than those in the other regions, in particular the South region. In all three regions the mean monthly GSIs decreased rapidly in March when annual sea surface temperatures were at their peak, and from April through to October the mean monthly GSIs remained at low levels indicating little reproductive activity of ovaries. The large error bars associated with the mean monthly GSIs during the November to March period highlight the considerable variability in the weight, and hence developmental stage, of ovaries during this period.

GSIs of male *G. hebraicum* showed a similar pattern to that of females (Fig. 4.1). However, the small size of testes, even during the spawning season, and necessity to estimate body weight from total length for most samples creates uncertainty in the interpretation of this data.

Histological analyses of *G. hebraicum* ovaries concured with the GSI data and showed that females with reproductively developed (stage 4) ovaries appeared in November in all three regions (Fig. 4.2). These data also indicated that spawning commenced in December and peaked from about January through to March, possibly with earlier peaks and a higher proportion of spawning females in the South region, although sample sizes from this region were low. The incidence of reproductively active ovaries dropped considerably in April, although minor spawning activity was still evident in May, at least in the North region. Of particular interest is the high proportion of non-spawning, mature ovaries (stages 2, 3 & 6) throughout the spawning season. These non-spawning ovaries typically showed signs of recent reproductive development, for instance, the presence of atretic yolk-globule stage oocytes or a high abundance of melano-macrophage centres and vascular tissue, and are therefore considered to have been reproductively developed (stage 4), and hence to have possibly spawned, during the current season. These ovaries occurred throughout the spawning period and comprised a particularly high proportion of the samples obtained from smaller females (Fig. 4.3). This phenomenon was evident in the different regions and also over successive years, and suggests that *G. hebraicum* has a complex, quite unique ovarian maturation cycle. This is also indicated by the high proportion of developing (stage 3) ovaries present throughout the non-spawning period.

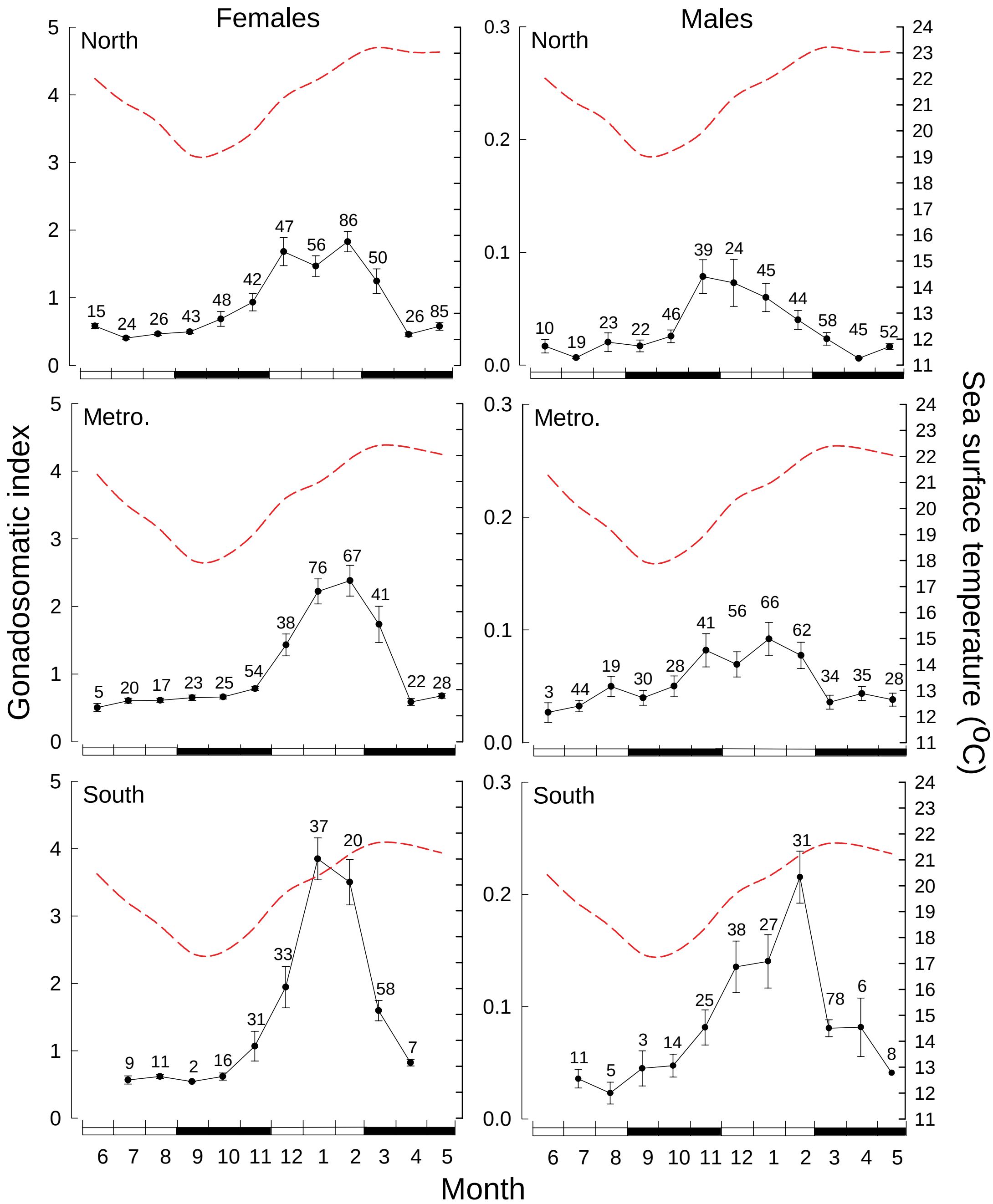

Figure 4.1. Mean monthly gonadosomatic indices (±1 SE, solid lines, sample sizes above) of females (left) and males (right) of *Glaucosoma hebraicum* ≥ L_{50} at maturity (Hesp *et al.* 2002) and corresponding mean monthly sea surface temperatures (°C, dashed lines) from the North, Metropolitan and South regions. On the x-axis, open rectangles represent winter and summer months and closed rectangles the spring and autumn months.

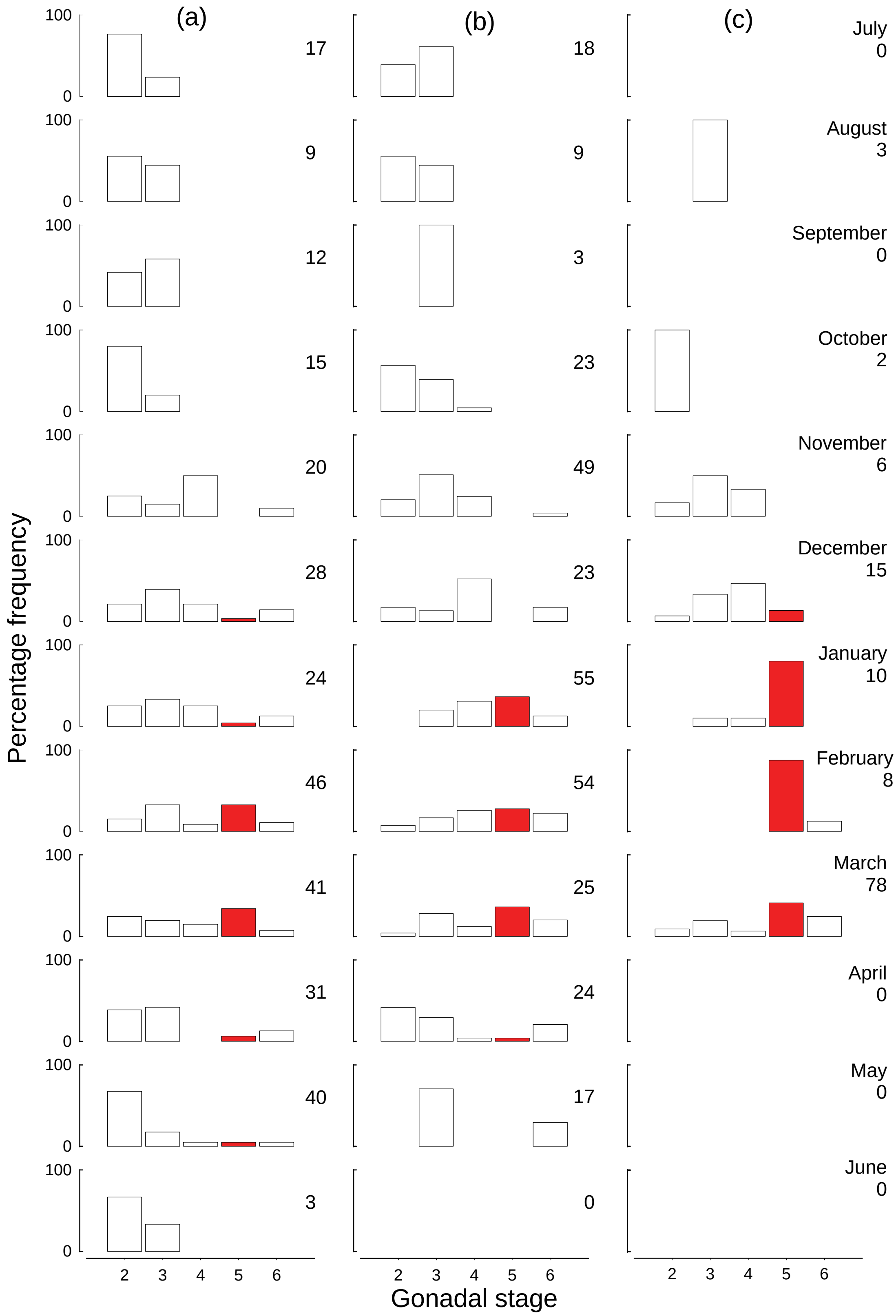

Figure 4.2. Percentage frequency of histologically-staged ovaries of *Glaucosoma hebraicum* ≥ L_{50} at maturity from the three regions a) North, b) Metropolitan and c) South. Data have been pooled for corresponding months and sample sizes are given for each month. Solid bars represent ovaries containing hydrated oocytes.

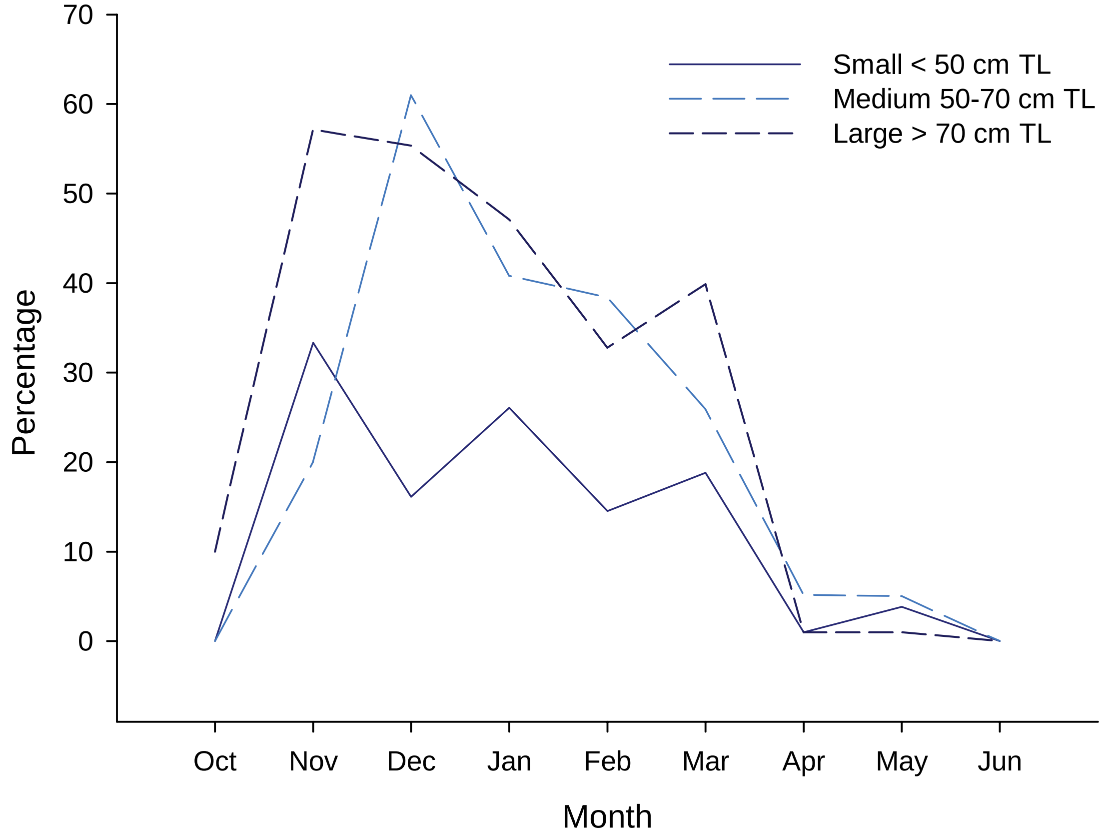

Figure 4.3. Percentage frequency of reproductively active (stages 4 & 5) ovaries of *Glaucosoma hebraicum* within samples obtained during the spawning season (data for each region and years 2003 – 2006 pooled). Data has been divided into three different size categories.

4.3.4 Batch fecundity

Batch fecundity is the total number of eggs released at one spawning event and was calculated for 78 *G. hebraicum* with ovaries confirmed histologically to have unovulated, hydrated oocytes (stage 5a). Batch fecundity increased with body size and ranged from *ca* 5,900 to 533,900 oocytes for 361 and 972 mm TL females, respectively (Fig. 4.4.).

No significant regional differences occurred between fish length and the number of hydrated eggs per gram of gonad produced (cube-root linear regression: N *vs.* M p-value = 0.96, N *vs.* S p-value = 0.88, Fig. 4.5). Data for batch fecundity from each region were subsequently pooled, with a cube-root linear model providing the best fit to describe the relationship between batch fecundity (total eggs) and total length (TL) (M. Craine, Dept of Fisheries, pers. comm.):

$$(\text{Total eggs})^{1/3} = -9.0569 + 0.0826\ \text{TL}, \; R^2 = 0.73, \; df = 76, \; \hat{\sigma} = 6.830$$

Due to the negative intercept, this model is valid for females > 109 mm TL. Further, because of the skewed variance in the raw data a bias correction term should be used in order to use this model to estimate an expected batch fecundity for a given fish length:

$$\text{Estimated total eggs} = \hat{\mu}^3 + 3\hat{\mu}\hat{\sigma}^2, \text{ where } \hat{\mu} = -9.0569 + 0.0826\ \text{TL},$$

with the 95% confidence intervals of the estimate being $(\hat{\mu} \pm 1.96\hat{\sigma})^3$.

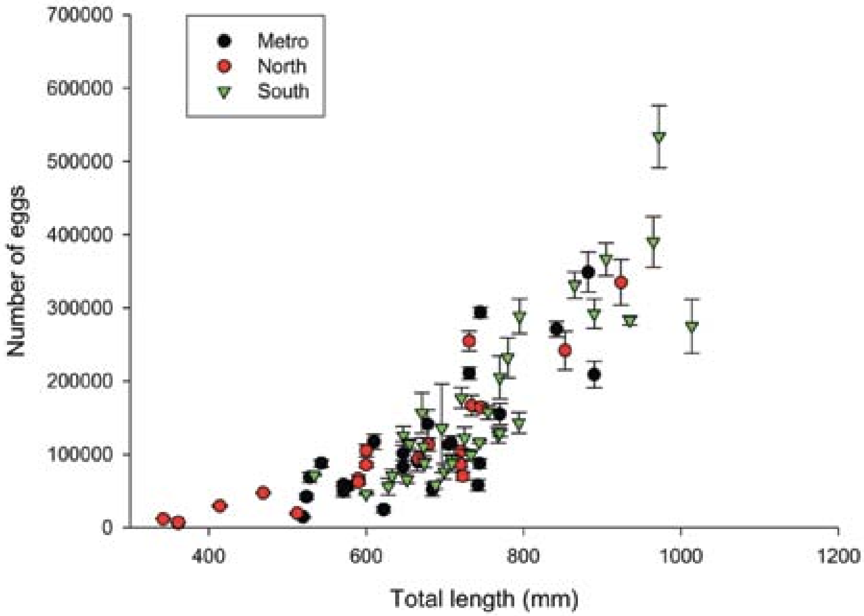

Figure 4.4. Relationship between batch fecundity and body size of female *Glaucosoma hebraicum* within each region (n = 78). Data show mean and SE of three replicate samples taken from ovaries that were confirmed histologically to contain unovulated hydrated oocytes (stage 5a).

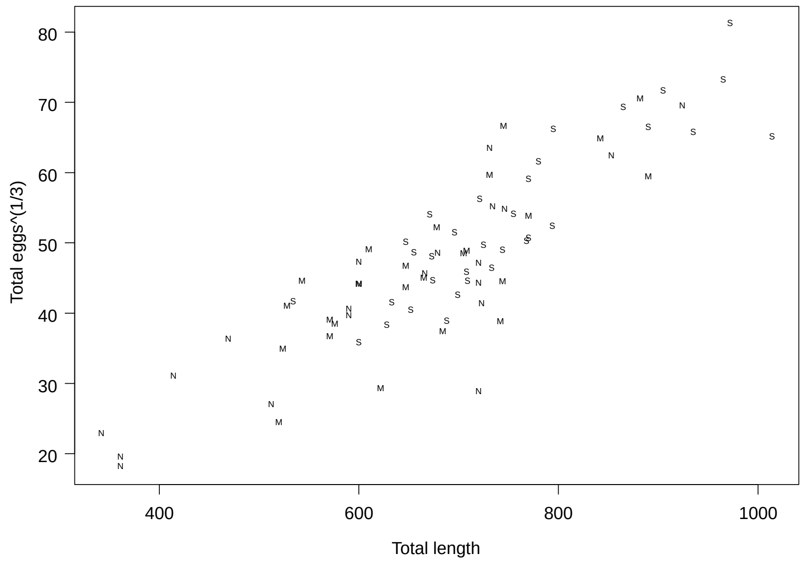

Figure 4.5. Relationship between cube-root transformed batch fecundity and body size of female *Glaucosoma hebraicum* from the North (N), Metropolitan (M) and South (S) regions (n = 78).

4.4 Discussion

The spawning period of *Glaucosoma hebraicum* is protracted, covering seven months from November (late spring) through to April (mid autumn). Within this period spawning activity peaks from January to March, with little temporal variation throughout the WCB. This is in contrast to *P. auratus*, which exhibits clear spatial differences in the timing of spawning activity in line with latitudinal gradients in water temperature (see Section 6.0). Also in contrast to *P. auratus*, the proportion of spawning female *G. hebraicum* does not generally appear to be high and there is a surprising abundance of non-reproductive individuals during the spawning period. This highlights distinct differences in reproductive strategies between these two species of fish, with *G. hebraicum* exhibiting a complex, socially controlled spawning pattern in which males appear to compete directly for spawning opportunities, whereas spawning activity by *P. auratus* is mainly influenced by environmental cues and males compete at the sperm level (see Section 6.0, Wakefield 2006; Mackie *et al.* 2009). As a consequence, male *G. hebraicum* have very small testes, secondary sexual characteristics (*e.g.* dorsal fin filament) and grow to a larger body size compared to females, whereas male *P. auratus* have large testes and in fact attain a slightly smaller body size to females (see Section 7.0, Wakefield 2006).

The high incidence of non-spawning ovaries also suggests cyclic levels of reproductive development in *G. hebraicum* ovaries during the spawning season. This differs to the pattern usually observed in marine, broadcast spawning species, in which the ovaries generally retain a high level of reproductive preparedness throughout the spawning season (*i.e.* stage 4 gonads), with occasional peaks in spawning activity (*i.e.* stage 5 gonads), usually in synchrony to environmental cues (*e.g.* see Section 6.0, Wakefield 2006, M. Mackie, pers. obs.). This strategy, which was evident in samples from two consecutive years, provides further evidence of a socially controlled spawning behaviour in which the ovaries of females (in particular smaller, less dominant individuals) may resorb vitellogenic oocytes when no spawning opportunities are available.

Evidence from histological analysis of ovaries collected during on-going monitoring will provide further information about this seemingly unusual strategy of ovarian development by female *G. hebraicum*. The histological data also highlighted the difficulty in using macroscopic criteria to stage *G. hebraicum* ovaries, even during the spawning season. The difficulty this poses in estimating size at maturity of this species is further compounded by the fact that small *G. hebraicum* (*i.e.* < 200 mm TL) are rarely encountered, even by experienced fishers. As such the best estimate of L_{50} at maturity remains that of Hesp *et al.* (2002), of 301 and 320 mm TL for females and males, respectively.

Batch fecundity of *G. hebraicum* follows the typical exponential curve in which larger-sized individuals produce extraordinarily high quantities of eggs per spawning episode. If, as appears to be the case, larger, more competitive females also spawn more frequently during the spawning season and, as has been found in black rockfish (*Sebastes melanops* Bobko & Berkeley 2004), have more viable eggs, then the importance of females to the spawning output of the population increases with body size. Larger male *G. hebraicum* are also likely to play a critical role in spawning output due to their competitive advantage (Mackie *et al.* 2009). Management of this species should therefore place importance on the complex spawning strategy, which includes a propensity to aggregate in small groups and hence potentially be more vulnerable to fishing activity (Sadovy & Domeier 2005; Mackie *et al.* 2009), as well as the protection of larger individuals, to ensure that spawning output of populations within the WCB are maintained.

5.0 Spatial and temporal comparisons of the age and growth of dhufish *Glaucosoma hebraicum* in the West Coast Bioregion

J. StJohn, C. Wakefield, I. Keay, and N. Jarvis

Objective 2 **To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction**

5.1 Introduction

The age and growth of *Glaucosoma hebraicum* was first studied using counts of growth zones on scales (Marr 1980). As fish scales can be partially resorbed or physically removed, ages of fish derived from this structure are typically under estimated (Casselman 1990; Campana & Thorrold 2001). The underestimation of ages derived from scales was reflected in a comparison between estimated ages from scales and sagittal otoliths for individuals of *G. hebraicum* (Marr 1980; Hesp *et al.* 2002). The sectioning of the sagittal otoliths has been identified as an important procedure for obtaining accurate age estimates of *G. hebraicum*, as the close proximity of opaque zones at the periphery of the otolith in older fish (> 6 years) make them indistinguishable when observed in whole otoliths and often result in an underestimate of age (Hesp *et al.* 2002). The trends exhibited by marginal increment analysis demonstrated that a single opaque zone is formed in the otoliths of *G. hebraicum* each year (Hesp *et al.* 2002). Thus, the number of opaque zones visible in sectioned otoliths of *G. hebraicum* can be used for ageing the individuals of this species (Hesp *et al.* 2002). The maximum ages recorded for females and males of *G. hebraicum* from sectioned otoliths are 39 and 41 years, respectively (Hesp *et al.* 2002).

Until recently, the only study that used ages derived from sectioned otoliths to describe the age composition and growth of females and males of *G. hebraicum* was for fish caught between Mandurah (32°32'S) and the Houtman Abroholos (28°35'S) from 1996 to 1998 (Hesp *et al.* 2002). The regional/latitudinal differences in the age compositions and growth of this species on the west coast of Western Australia has not been investigated.

The aims of this study of the age and growth of *G. hebraicum* were as follows. 1) Determine the length and age compositions within the North, Metropolitan and South regions, for each year from 2002 to 2006. 2) Compare the growth of females and males between the three regions within the WCB. 3) Use the age composition data to determine the extent of variation in the relative abundances of year classes and thereby an indication of inter-annual variations in recruitment. 4) Determine the extent to which recruitment is related to environmental variables.

5.2 Methods

Details of sample collection and otolith preparation are given in Section 2.0.

5.2.1 Otolith interpretation

Glaucosoma hebraicum sections were examined microscopically under reflected light against a black background as described by Hesp *et al*. (2002). Opaque zones were counted along a common axis from the primordium to the proximal edge (Fig. 5.1). Initially, a number of sections were read once by two independent readers (primary reader IK and secondary reader NJ). Comparison of opaque zone counts for these sections indicated that most of the variation in the final counts were due to difficulty in identification of the first two opaque zones. A template outlining the spacing between the first three opaque zones was developed and used by the two readers to read every otolith section. The number of opaque zones, outer margin classification (i.e. translucent or opaque) and the readability index were recorded for each otolith (Tables 5.1 & 5.2).

Differences in opaque zone counts between readers were examined using count frequency tables and count bias graphs, and precision calculated as an index of average percentage error (IAPE, Beamish & Fournier 1981; Campana *et al.* 1995).

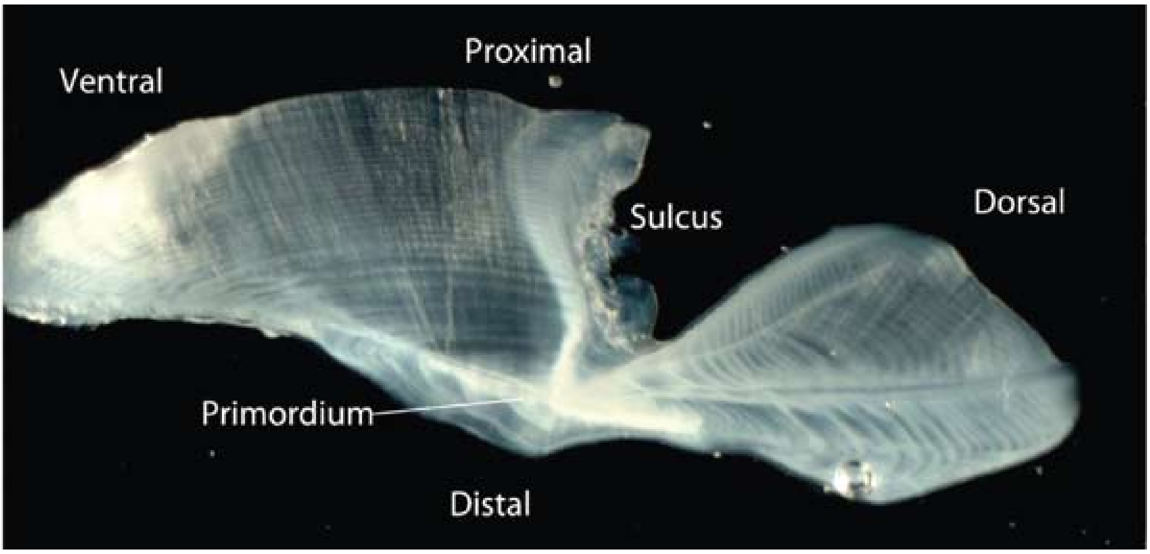

Figure 5.1. Image of a transverse section of a *G. hebraicum* otolith under reflected light showing the primordium, sulcus, and proximal, distal, dorsal and ventral edges.

Table 5.1. Classification of outer margin of sections of otoliths of *G. hebraicum***.**

Category	Otolith margin appearance
Opaque	Opaque margin
Thin translucent	Translucent margin is less than 50% developed as compared to the previous translucent zone
Wide translucent	Translucent margin is 50% or more developed as compared to the previous translucent zone

Table 5.2. Readability index categories used with *G. hebraicum* otoliths.

Category	Readability
0	Unreadable
1	Very Poor
2	Poor
3	Fair
4	Good
5	Perfectly readable

5.2.2 Age determination

A protocol for converting opaque zone counts to decimal ages was developed and was adapted from those used for Spanish mackerel (Lewis & Mackie 2002), southern sea garfish (Jones *et al.* 2002) and grass emperor (Ayvazian *et al.* 2004b). This approach provides greater resolution in the subsequent growth analyses compared with integer ages, and requires opaque zone counts, outer margin classification, a generalized birth date, and month of capture for each fish.

Where the outer margin classification was not able to be determined, the section was excluded from the subsequent aging analysis. This tended to be the case for otolith sections of fish captured in months during the period of delineation of the opaque zone.

The algorithm used to convert opaque zone counts to ages in *G. hebraicum* was the same for every region because the timing of spawning was similar throughout the bioregion (see Section 4.0). In *G. hebraicum* the examination of otolith margins showed that opaque zones were delineated between September and December, which coincided with the onset of reproductive activity. Similar to Hesp *et al*. (2002), the generalized birth-date representing the month of peak spawning in this study was assigned as February 1. Thus, the age of each *G. hebraicum* on its date of capture in each region was estimated, using a combination of the birth date, the time of year when the opaque zones on the otoliths of the majority of *G. hebraicum* become delineated in that region, the time of formation of the first opaque zone and the number of opaque zones.

The age of the fish was final if the calculated age, based on the count of opaque zones and the classification of the outer margin of the otolith section, was the same for both readers. This included those occurrences when the readers' counts and outer margin classifications differed but their calculated ages agreed, and the otolith was assigned the count and outer margin classification from the primary reader. When the calculated age differed between readers, however, the otolith was re-examined by both readers. If the calculated age of the re-readings were in agreement, then it became the final age, otherwise the otolith was rejected.

5.2.3 Growth

A von Bertalanffy growth curve was used to model the growth of *G. hebraicum* in the three regions (North, South & Metropolitan). The von Bertalanffy growth equation is

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

where L_t = mean length of fish (TL, mm) at age t (year);

L_∞ = mean asymptotic length (TL, mm);

k = growth coefficient (year^{-1});

t = age of fish (year);

t_0 = hypothetical age (years) at which mean length is zero if fish had always grown at the rate described by the equation.

Parameters of the von Bertalanffy growth curves for each sex in each region were compared using a likelihood-ratio test (Kimura 1980) under the assumption that residual variances differed (Cerrato 1990).

5.2.4 Environmental variables

The dispersal of progeny of *G. hebraicum* during late spring and summer, *i.e.* its spawning period, is subject to the counter-flowing Leeuwin and Capes Currents. The two parameters commonly used to predict the relative strength of the southward flowing, offshore Leeuwin Current include sea level (measured at Fremantle) and the Southern Oscillation Index (SOI). Higher than average sea levels and positive SOI values represent stronger Leeuwin Current flows or *La Nina* events. Conversely, lower values of these parameters represent weaker Leeuwin Current flows or *El Nino* events (Pearce & Phillips 1988; Feng *et al.* 2003).

The Capes Current flows northward in nearshore, continental shelf waters (Gersbach *et al.* 1999; Pearce & Pattiaratchi 1999). There is no direct indicator of the strength of the Capes Current. As it appears to be dominantly wind-driven (Gersbach *et al.* 1999), the alongshore wind speed measured at Cape Naturaliste averaged from December to February has been used as a proxy, with higher northwards winds representing a stronger Capes Current. To a lesser extent variations in salinity may also provide additional information on the strength of the Capes Current, although this parameter is highly influenced by processes associated with nearshore evaporation.

Wind data were obtained from the weather station at Cape Naturaliste (Pearce & Pattiaratchi 1999). The mean northward component of the wind speeds (m/s) from Cape Naturaliste between December and February each year from 1983 to 2005 was used as an annual estimate of the relative strength of the Capes Current during the peak spawning period of *G. hebraicum* (see Section 4.0).

Monthly salinity and temperatures of surface and bottom waters have been measured in four locations in the WCB since 1982 by the Department of Fisheries, Western Australia. Salinity and water temperature measurements were taken in the waters near Dongara and Jurien in the North region and Fremantle and Lancelin in the Metropolitan region. These variables were measured using a WTW Model 315i electrical conductivity meter equipped with a tetraCon 325 measuring cell and an integrated negative temperature coefficient (NTC) thermistor. The electrical conductivity was converted to a salinity value on the (unitless) Practical Salinity Scale using the equation in Culkin and Smith (1980). The metre and cell were calibrated according to the manufacturer's specifications and their performance was checked against 'standard' seawater with a certified salinity value of 34.999 (IAPSO Standard Seawater, Ocean Scientific International). Where temperature measurements were unavailable, annual mean sea surface temperatures (SST) were calculated to two decimal places measured from satellite images (Reynolds 1988; Reynolds & Smith 1994).

5.3 Results

5.3.1 Contribution of fish samples from each sector

A total of 1,663, 1,100 and 813 *G. hebraicum* were collected from the North, Metropolitan and South regions, respectively, between 2002 and 2006 (Table 5.3). These fish were obtained in varying proportions from different user groups from the commercial, recreational and research sectors. In the North region the majority of fish were obtained from commercial fishers (*ca* 84 %), compared to *ca* 10 and 6 % from recreational (including fishing clubs) and research, respectively (Table 5.3). In contrast, the majority of fish collected in the Metropolitan region were obtained from recreational fishers (*ca* 82 %, including fishing charters and fishing clubs), compared to *ca* 14 and 4 % from commercial and research, respectively (Table 5.3). In the South region, *ca* 64 and 34 % of fish were obtained from the recreational and commercial sectors, respectively, with research comprising only 2 % in this region (Table 5.3).

Table 5.3. Number of *Glaucosoma hebraicum* obtained from each sector in each of the three regions in 2002, 2003, 2004, 2005 and 2006.

Region	Sector	Year					%
		2002	2003	2004	2005	2006	
North	Commercial	91	769	285	236	22	84
	Recreational						
	Fishing club			38		44	5
	Other		2	3	74	1	5
	Research	8	32	4	54		6
	Total	**99**	**803**	**330**	**364**	**67**	**1663**
Metropolitan	Commercial	33	51	33	42		14
	Recreational						
	Fishing club		14	140	213	49	38
	Fishing charter		7	22	17	2	4
	Other	1	25	190	150	68	39
	Research	2	7	25	2	7	4
	Total	**36**	**104**	**410**	**424**	**126**	**1100**
South	Commercial		48	61	85	81	34
	Recreational						
	Fishing club		32	53	121	112	39
	Other	24	19	64	74	26	25
	Research			1	12		2
	Total	**24**	**99**	**179**	**292**	**219**	**813**
Grand total		**159**	**1006**	**919**	**1080**	**412**	**3576**

5.3.2 Bias and precision of opaque zone counts

The counts of opaque zones between two readers from 587 sectioned otoliths agreed for *ca* 55 % of fish or were within one for *ca* 95 % of fish (Table 5.4). The IAPE between the estimated counts of opaque zones of the two readers was 3.06 % (Fig. 5.2). Thus, this percentage error was well within the acceptable levels suggested by Campana (2001), of < *ca* 5 % for species of moderate longevity and reading complexity. When the counts of opaque zones of sectioned otoliths differed between readers, the two readers conferred to obtain an agreed age for each of these fish.

Table 5.4. Comparison of counts of opaque zones in otoliths of *Glaucosoma hebraicum* between two readers. Data are numbers of fish and squares represent identical counts.

Opaque zone counts from Reader 1	Opaque zone counts from Reader 2: 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
3	6	1																				7
4	4	6	2																			12
5		7	20	5																		32
6		2	13	30	6																	51
7			2	24	58	14	3															101
8				1	16	51	12	1														81
9				2	3	23	38	13														79
10					1		20	47	16			1										85
11							3	18	36	11	2											70
12									6	7	2	1										16
13										3	5	5										13
14										1	2	4	1									8
15											1	2	4		1							8
16													1	3	2							6
17														1		1						2
18														1	2	3						6
19															1		1					2
20																	3	3				6
21																		1	1	1		3
22																				2		2
23																				1		1

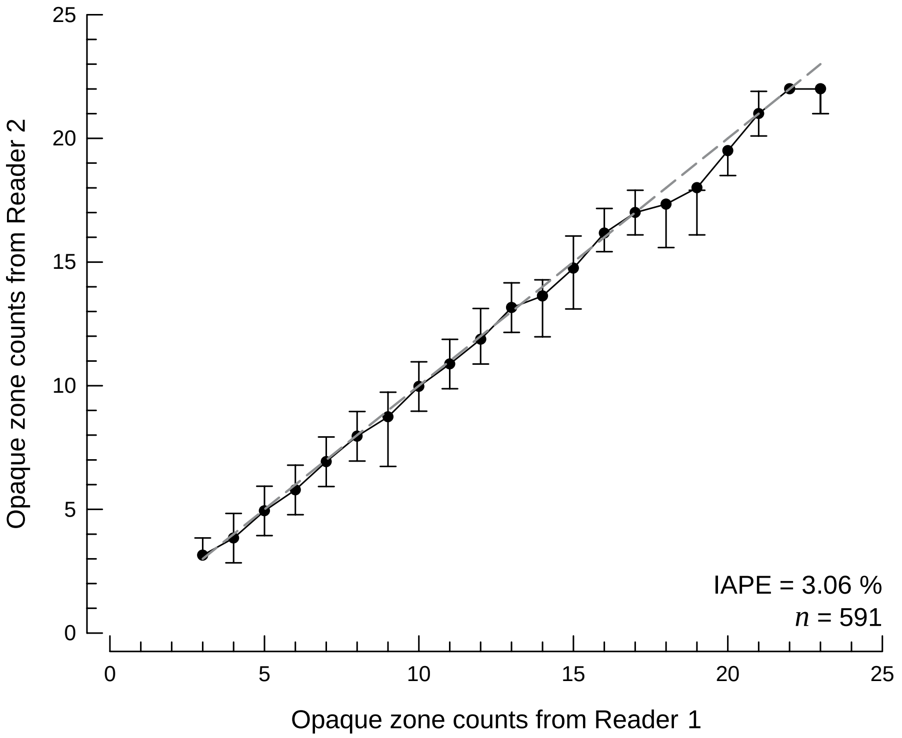

Figure 5.2. Comparison of opaque zone counts in the otoliths of *Glaucosoma hebraicum* between two readers (from Table 5.4). Error bars represent 5 and 95 percentiles and the dashed line the 1:1 equivalence. IAPE, index of average percentage error.

5.3.3 Length and age compositions

As the majority of fish were obtained by commercial and recreational fishers, *G. hebraicum* less than the minimum legal length (MLL) of 500 mm TL were poorly represented in samples. The length compositions of the females and males of *G. hebraicum* varied significantly (Kolmogorov Smirnoff test, $p < 0.001$), with a higher proportion of males > *ca* 800 mm TL in each region (Fig. 5.3). The length compositions of females and males also varied significantly between the North, Metropolitan and South regions (Kolmogorov Smirnoff test, $p < 0.001$ for all combinations). The length composition of the females of *G. hebraicum* in the North region displayed a precipitous decline in the numbers of fish at lengths > *ca* 680 mm TL, which was not as pronounced in the length compositions of females from the Metropolitan and South regions (Fig. 5.3). In addition, there were relatively fewer females of *G. hebraicum* > 900 mm TL caught in the North region compared to the Metropolitan and South regions (Fig. 5.3). The length composition of the males of *G. hebraicum* in the North region also displayed a precipitous decline in the numbers of fish at lengths > *ca* 860 mm TL, which was also not as pronounced for males from the Metropolitan and South regions (Fig. 5.3). In addition, there were also relatively fewer large male *G. hebraicum* (> 1000 mm TL) caught in the North region compared to the Metropolitan and South regions (Fig. 5.3). The length composition of the males of *G. hebraicum* in the South region had higher numbers of fish between 760 and 860 mm TL, this was also paralleled but to a lesser extent in the length composition of males in the Metropolitan region (Fig. 5.3). This situation was not evident in the length compositions of female *G. hebraicum* in these two regions.

The age composition of *G. hebraicum* in the South region in 2003 was dominated by fish between seven and ten years of age, with very few fish older than ten years (Fig. 5.4). This trend was also consistent in the age compositions of *G. hebraicum* in the South region in consecutive years, *i.e.* 2004, 2005 and 2006, where the majority of fish were from the 1993 to 1996 year classes and relatively few fish were from the 1992 year class and older. However, in 2006 the age composition also comprised a relatively high number of seven year old fish, which represented the 1999 year class (Fig. 5.4). *NB* although the spawning period of female *G. hebraicum* occurs predominantly from December to March each year the highest GSIs and prevalence of ovaries with hydrated oocytes occurs in February (see Section 4.0), thus a year class relates to February of that year, *e.g.* the 1993 year class represent spawning from December 1992 to March 1993.

In the Metropolitan region, the age composition of *G. hebraicum* in 2002 was dominated by fish between six and nine years of age, with very few fish older than nine years (Fig. 5.4). Like the South region, the majority of fish in the Metropolitan region in 2002 were from the 1993 to 1996 age classes. These age classes also dominated the catches in the Metropolitan region in the following years from 2003 to 2006 (Fig. 5.4). As was the situation in the South region, the age composition in the Metropolitan region in 2006 also had a relatively high number of seven year old fish, which represented the 1999 year class (Fig. 5.4).

The high abundances of four year classes, *i.e.* 1993 to 1996, that dominated the catches of *G. hebraicum* in the Metropolitan and South regions, was not evident in the age compositions from the North region. The age composition of *G. hebraicum* in the North region in 2002 had a relatively high abundance of six year old fish with the numbers of fish declining in subsequent year classes till *ca* 21 years. However, there was a relatively high abundance of nine year old fish in that year, which represented the 1993 year class (Fig. 5.4). The 1993 year class also had relatively high numbers of individuals at 10, 11, 12 and 13 year of age in the age compositions in 2003, 2004, 2005 and 2006, respectively (Fig. 5.4). Thus, the 1993 year class appeared to represent a year of strong recruitment in all three regions and the 1994, 1995, 1996 and 1999 year class representing strong recruitment in the two more southern regions, *i.e.* Metropolitan and South, on the west coast of Western Australia.

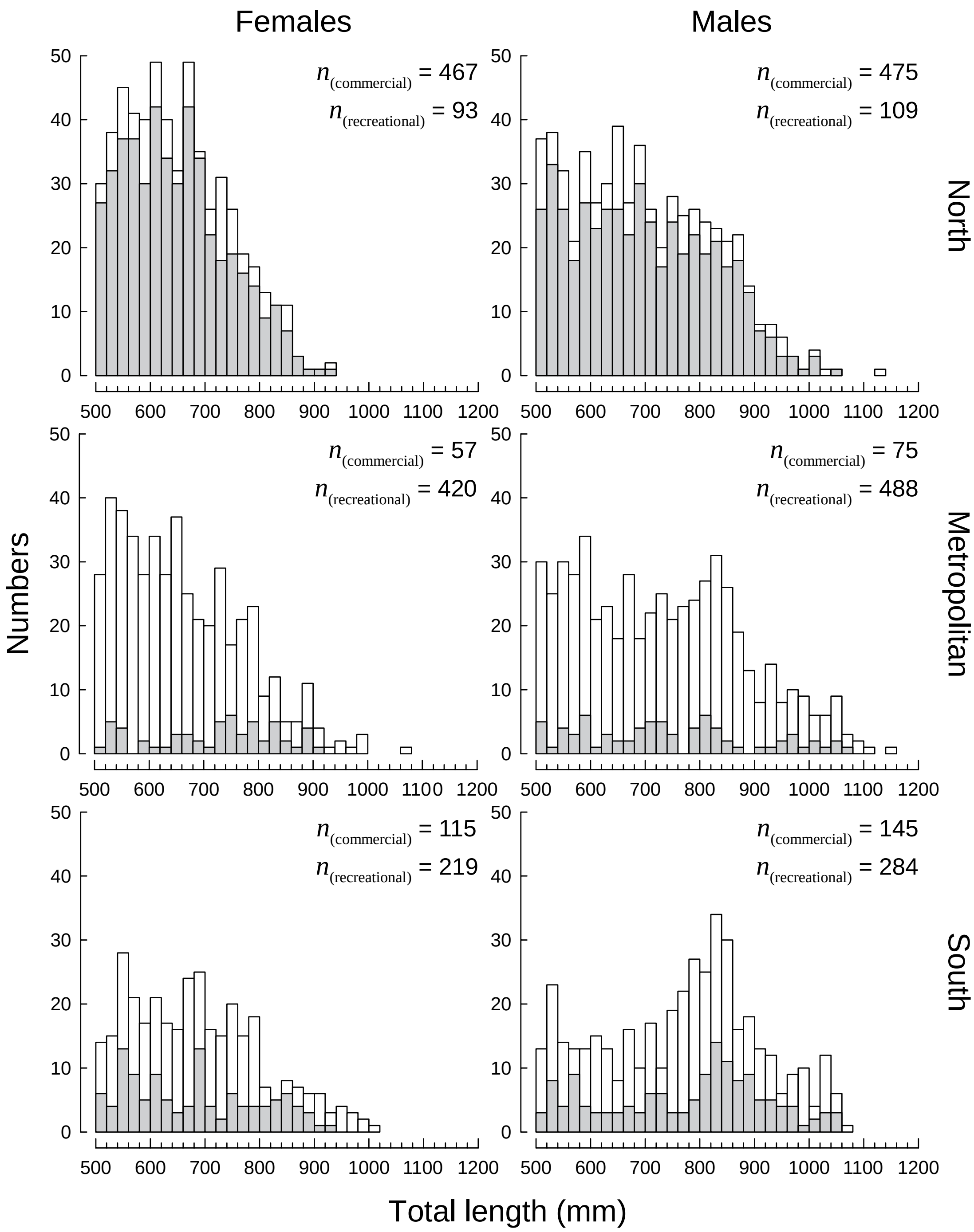

Figure 5.3. Length frequency histograms for commercially (grey bars) or recreationally (white bars) caught females (left) and males (right) of *Glaucosoma hebraicum* from the North (above), Metropolitan (middle) and South (below) regions between 2002 and 2006.

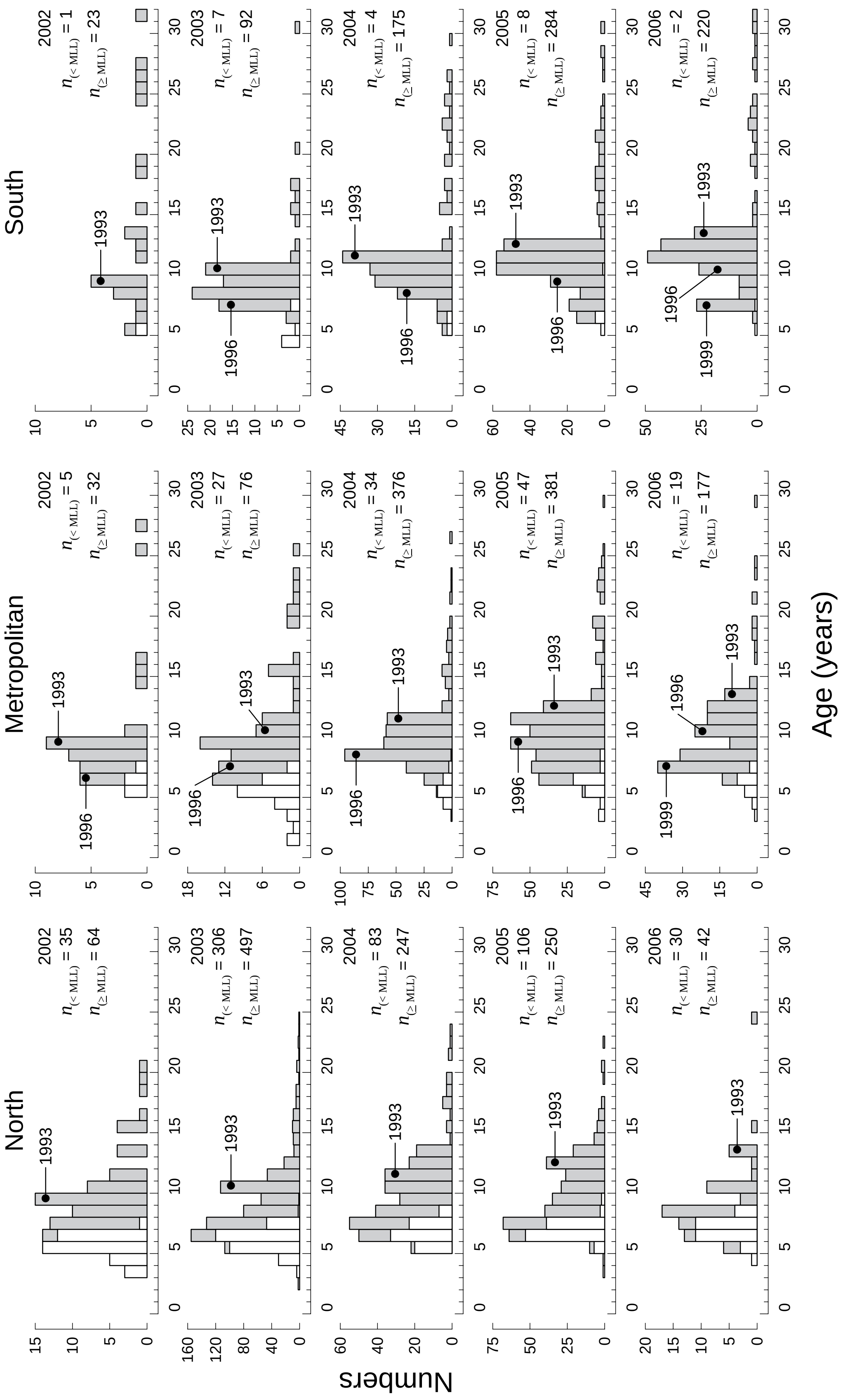

Figure 5.4. Age frequency histograms of *Glaucosoma hebraicum* < Minimum Legal Length (500 mm TL, white bars) and ≥ MLL (grey bars) for fish caught in the North (left), Metropolitan (middle) and South (right) regions in each year between 2002 and 2006.

5.3.4 Growth

The von Bertalanffy growth curves provided good fits to the total lengths at age of the females and males of *G. hebraicum* in each of the North, Metropolitan and South regions, as was demonstrated by the high values for the coefficient of determination for those curves that ranged from 0.77 to 0.92 (Table 5.5). However, the relatively low numbers of females and males younger than 5 years and older than 13 years in each region resulted in positive values of t_o for each curve (Table 5.5, Fig. 5.5). Thus, the von Bertalanffy parameters provided in this study describe the growth of *G. hebraicum* within the legally exploitable range, i.e. ≥ the MLL of 500 mm TL, in each region. As this was consistent among regions comparisons of growth between regions could be made.

The von Bertalanffy growth curves for females and males differed between each other and among those of the same sex in each of the three regions (likelihood ratio test, $p < 0.05$). However, the estimated lengths from the von Bertalanffy equation of females at 15 years of age, *i.e.* 765, 800 and 789 mm TL, from the North, Metropolitan and South regions, respectively, were similar with the North and South regions differing by 4.4 and 1.4%, respectively from the Metropolitan region and 3.0% from each other. Likewise, the estimated lengths, from the von Bertalanffy equation, of males at 15 years of age, *i.e.* 879, 921 and 895 mm TL, from the North, Metropolitan and South regions, respectively, were also similar with the North and South regions differing by 4.6 and 2.8%, respectively from the Metropolitan region and 1.8% from each other. In contrast, the differences in the estimated lengths between females and males at 15 years of age in each region were much larger, *i.e.* 13.0, 13.1 and 11.8% for the North, Metropolitan and South regions respectively. Thus, the detection of a statistically significant difference between the von Bertalanffy growth curves of the same sex in each region reflects the sensitivity of the likelihood ratio test when the sample sizes are large and are considered of limited biological significance. However, the statistically significant difference between the growth curves of females and males in each region was considered to be also biologically significant given the large differences in their estimated lengths at older ages. More specifically, the difference in the growth between sexes in each region was a reflection of the von Bertalanffy growth equations where L_∞ was consistently larger for males than for females (Table 5.5, Fig. 5.5). Considering a common growth curve is traditionally used for assessing the status of this species, the length at age data for each sex have been combined for the three regions and the von Bertalanffy growth parameters are given in Table 5.5.

Table 5.5. von Bertalanffy growth parameters (± 95% CI) for females and males of *Glaucosoma hebraicum* in the North, Metropolitan and South regions and all three regions combined.

	L_∞ (mm, TL)	*k* (yr-1)	t_o (yr)	Amax	TL_{max}	*n*	r^2
North							
Female							
Estimate	937	0.12	0.85	23.3	924	744	0.82
Upper	983	0.14	1.30				
Lower	892	0.10	0.40				
Male							
Estimate	1125	0.11	1.17	24.0	1120	817	0.89
Upper	1179	0.13	1.48				
Lower	1070	0.10	0.86				
Metro.							
Female							
Estimate	1047	0.10	0.54	25.8	1075	428	0.86
Upper	1102	0.12	1.00				
Lower	992	0.09	0.09				
Male							
Estimate	1178	0.11	1.17	29.0	1150	519	0.92
Upper	1215	0.12	1.46				
Lower	1142	0.10	0.89				
South							
Female							
Estimate	992	0.11	0.57	31.8	1014	255	0.77
Upper	1051	0.13	1.73				
Lower	934	0.09	-0.59				
Male							
Estimate	1066	0.14	1.92	30.2	1070	323	0.85
Upper	1102	0.16	2.47				
Lower	1030	0.12	1.38				
Regions combined							
Female							
Estimate	983	0.11	0.75			1506	0.83
Upper	1015	0.12	1.03				
Lower	957	0.10	0.44				
Male							
Estimate	1128	0.12	1.31			1638	0.90
Upper	1152	0.12	1.47				
Lower	1106	0.11	1.12				

L_∞, hypothetical asymptotic length at an infinite age, TL, total length, *k*, growth coefficient, t_o, hypothetical age at zero length, A_{max}, maximum age, TL_{max}, maximum total length, *n*, sample size, r^2, coefficient of determination.

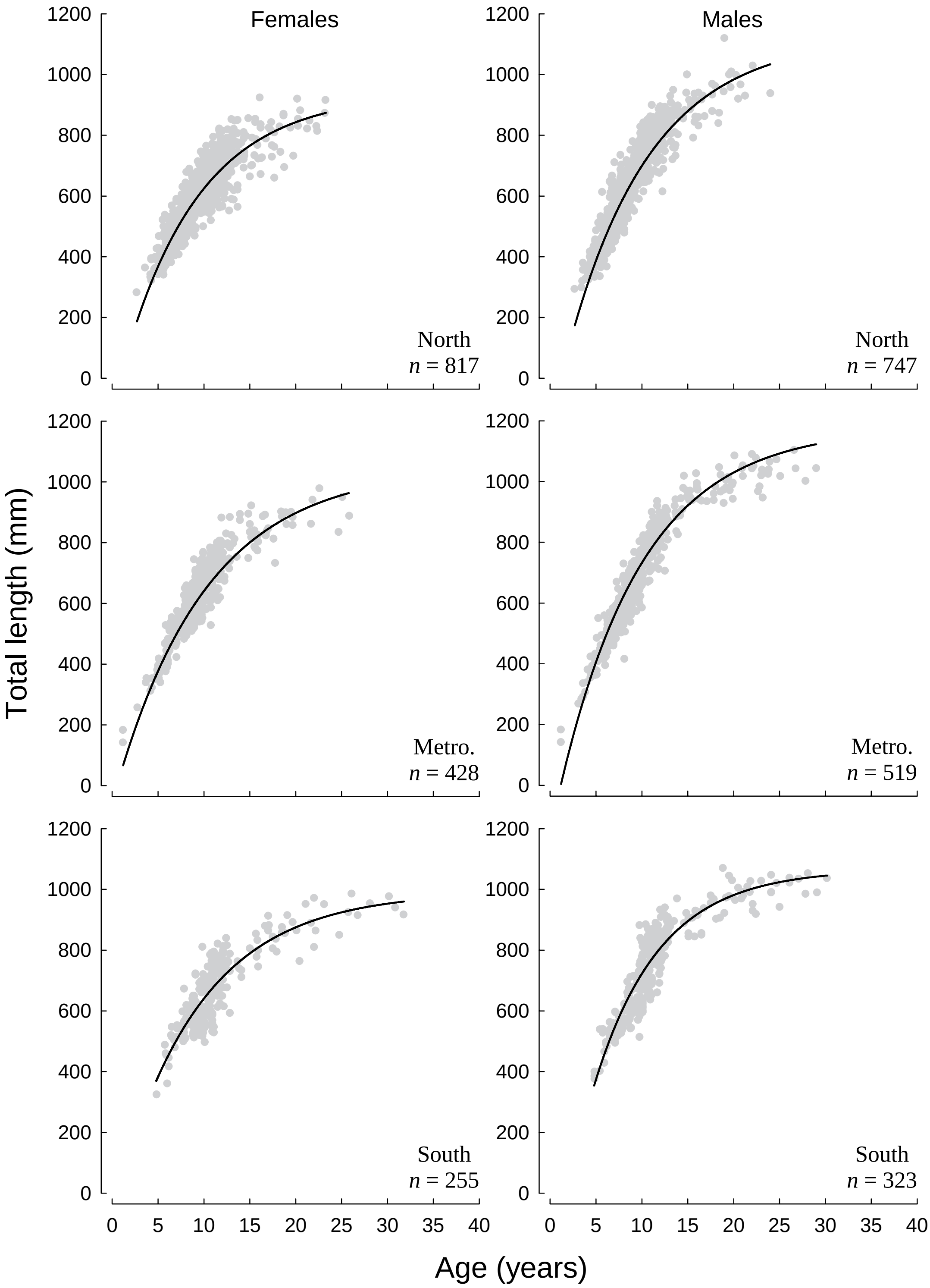

Figure 5.5. von Bertalanffy growth curves fitted to lengths at age of females (left) and males (right) of *Glaucosoma hebraicum* from the North, Metropolitan and South regions.

5.3.5 Recruitment and environmental variables

The Metropolitan and South regions displayed very similar trends in the variations in year class strength based on the age frequency distributions from 2002 to 2006. The year classes that displayed the highest abundances of *G. hebraicum* occurred in four consecutive year classes from 1993 to 1996 and in 1999. In the North region there appeared to be only one year class for which abundances of *G. hebraicum* were relatively high, *i.e.* 1993. It would be difficult to determine the relative contribution of recruits to the adult populations of *G. hebraicum* from year classes older than 1993 in each region based on age frequencies. The current low numbers of *G. hebraicum* from year classes older than 1993 may reflect a longer exposure time to fishing mortality, with the levels of fishing mortality over this period difficult to measure as they have most likely been increasing. Alternatively, they may also represent years of poor recruitment. The relationships between recruitment and environmental variables in this study are restricted to the relative numbers of *G. hebraicum* in year classes that are represented in relatively high abundances in samples that were collected between 2002 and 2006.

The five year classes that appeared to have high abundances of individuals based on their age compositions, *i.e.* 1993 to 1996 and 1999, occurred during years of both strong and weak Leeuwin current events based on variations in the sea level at Fremantle (Fig. 5.6) and the SOI (Fig. 5.7). There thus appears to be little if any direct correlation between the Leeuwin Current and recruitment of *G. hebraicum*.

A combination of mean wind speeds at Cape Naturaliste and mean salinities measured at four locations along the WCB between December and February each year were used to predict the relative annual strength of the Capes Current. Since 1983, there have been four years of both higher than average wind speeds and salinity, *i.e.* 1994, 1996, 2003 and 2004 (Fig. 5.8). Of these four years both 1994 and 1996 have been noted as having relatively higher abundances of individuals based on age composition data, whereas the relative recruitment abundances of the 2003 and 2004 year classes are unknown as a large majority of individuals from these two year classes are yet to have recruited into the fishery. In contrast, there has been essentially five years of both lower than average wind speeds and salinity, *i.e.* 1983, 1988, 1989, 1990 and 1992 (Fig. 5.8). These five years most likely represent less than average current strengths of the Capes Current, with four out of five of these years preceding the 1993 to 1996 year classes that appeared to have higher abundances of *G. hebraicum*. The remaining years have had various combinations of high, low or average wind speeds and salinity, including 1993, 1995 and 1999, which have been recognised as having higher abundances of individuals based on age composition data.

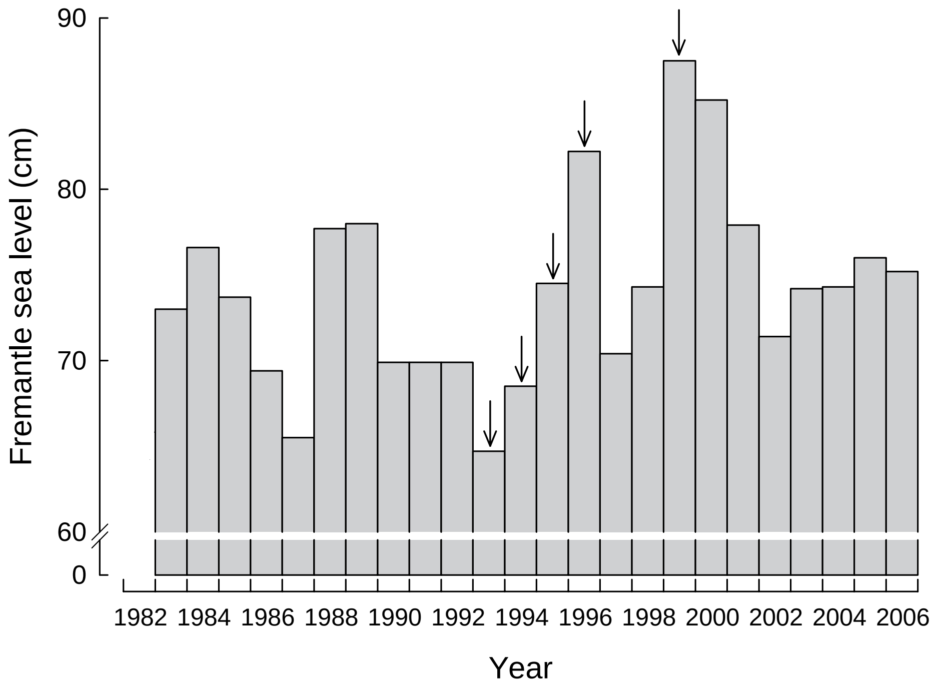

Figure 5.6. Mean annual sea levels at Fremantle. Arrows indicate years of relatively high abundances of recruits.

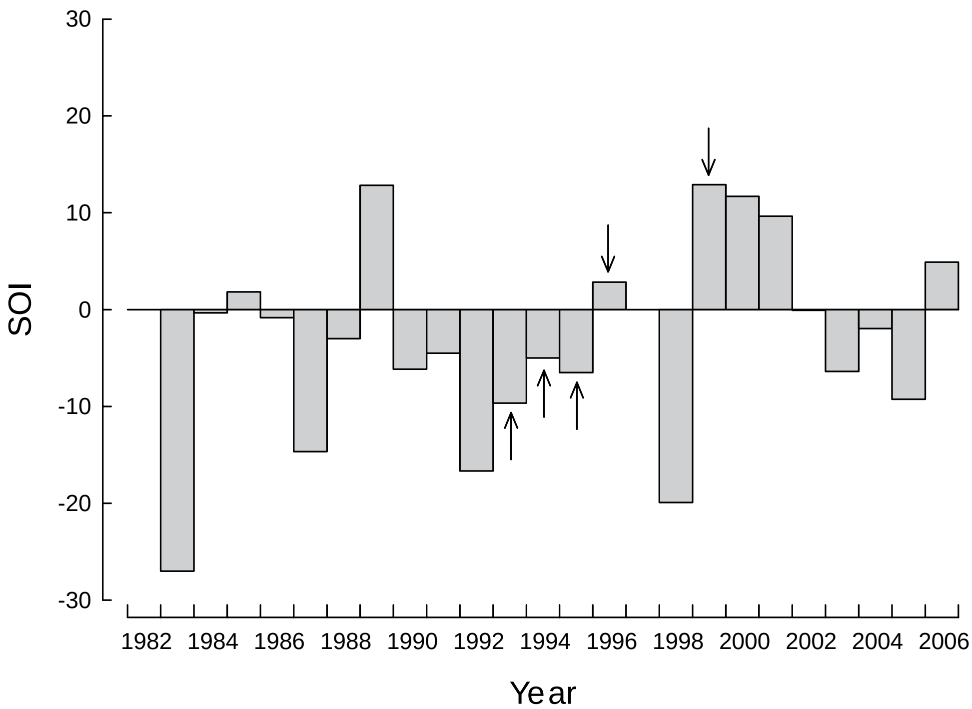

Figure 5.7. Mean values of the Southern Oscillation Index (SOI, see Section 5.2.4) from months that correspond to the spawning period of *G. hebraicum* each year, *i.e.* November to April, where the year corresponds to year classes that are accorded to the month with the highest prevalence of spawning, *i.e.* February. Arrows indicate years of relatively high abundances of recruits.

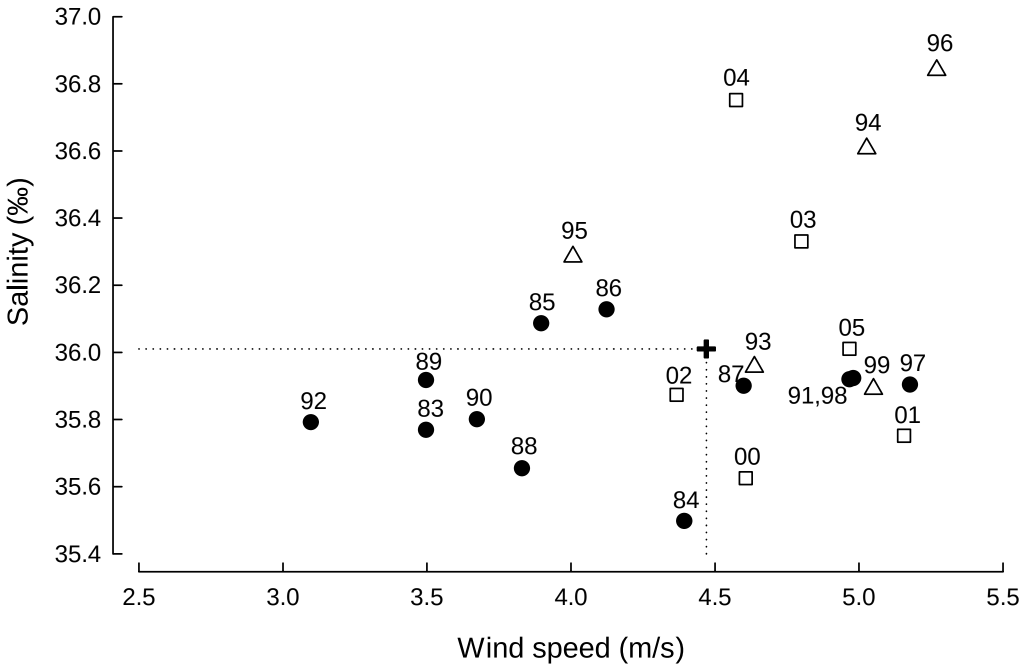

Figure 5.8. Mean salinities (‰) and northward component of the wind speeds (m/s) from Cape Naturaliste between December and February for each year from 1983 to 2005, where the year corresponds to year classes that are accorded to the month with the highest prevalence of spawning, *i.e.* February (see Section 2.4.2). Triangles represent year classes with relatively strong recruitment, circles represent year classes with average or below average recruitment and squares represent year classes that have not yet recruited into the fishery. Dashed lines represent average wind speeds and salinities of 4.47 m/s and 36.01 ‰, respectively.

5.4 Discussion

5.4.1 *Age compositions and growth*

The majority of *Glaucosoma hebraicum* in this study were obtained by commercial and recreational fishers who are obliged to adhere to the minimum legal length (MLL) of 500 mm TL, thus fish less than the MLL were poorly represented in samples. The age compositions of *G. hebraicum* in the Metropolitan and South regions contained relatively few fish older than the 1993 year class, *i.e.* 9 to 13 years of age in 2002 to 2006, respectively. In the North region, the age composition displayed more of a gradual decline in the numbers of each year class from the age at which they were fully recruited into the fishery (> *ca* 8 years), which is typical of high levels of fishing pressure on a long lived species (Wise *et al.* 2007). The maximum ages recorded for females and males were *ca* 32 and 30 years, respectively, which is 7 and 11 years less than that recorded for females and males, respectively, in 1996-98 (Hesp *et al.* 2002).

The growth of *G. hebraicum* differed significantly between females and males in all three regions, such that the males of this species attained a larger size than the females. This is consistent with the only previous study of the growth of *G. hebraicum* that estimated ages of individuals based on sectioned otoliths (Hesp *et al.* 2002). Comparisons between the parameters of the von Bertalanffy growth curves between the previous study (Hesp *et al.* 2002) and this current study could not be made because of the large differences between the values of t_0 (hypothetical length at zero age).

This study provided the first regional comparison of the growth of *G. hebraicum*. The growth of females of this species was not significantly different between the North, Metropolitan and South regions. Likewise, the growth of males of *G. hebraicum* was also not significantly different between these regions. Thus, a single von Bertalanffy growth curve for both females and males can be used to describe the growth of *G. hebraicum* in the WCB.

5.4.2 Variations in year class strength and environmental variables

The regional analysis of age compositions of *Glaucosoma hebraicum* has provided insight into the latitudinal variability in the relative strengths of year classes in the WCB. In the Metropolitan and South regions, the 1993 to 1996 year classes appeared to contribute relatively higher numbers of fish to the catches from 2002 to 2006, with relatively few fish older than the 1993 year class represented despite fish older than 30 years being caught. In comparison, only the 1993 year class appeared to contribute relatively high numbers of *G. hebraicum* to the age compositions in the North region. In this region all other year classes, once fully recruited into the fishery (> *ca* 8 years), appeared to contribute relatively similar numbers in the catches from 2002 to 2006.

The spawning period of *Glaucosoma hebraium* occurs from November to April, with a peak spawning period from December to February (see Section 4.0, Hesp *et al.* 2002). Spawning generally takes place in the vicinity of limestone or coral reef formations at various depths (10 to 150 m) throughout shelf waters of the WCB (see Section 4.0, Hesp *et al.* 2002). During this period there are two opposite-flowing mesoscale currents that potentially influence the survivability and dispersal of progeny of *G. hebraicum*, *i.e.* the Capes and Leeuwin Currents. The Capes Current is generated at the southwest capes of Western Australia and flows northward in continental shelf waters and is thought to retain pelagic eggs and larvae in these shelf waters. The Leeuwin Current generally transports relatively low saline and nutrient poor water southward in offshore waters adjacent to the Capes Current, and during late spring and summer is generally restricted from shelf waters by the influence of the Capes Current (Pearce & Pattiaratchi 1999; Muhling *et al.* 2008). Currently, there are no environmental parameters available that can accurately determine the strength and productivity of the Capes Current. However, the wind velocity at the southwest capes region during late spring and summer are able to provide proximal estimates of the annual strength of the Capes Current and thus information on the potential dispersal of progeny. This study has also examined annual variations in salinity considering the Capes Current is generally more saline than the Leeuwin Current. This environmental parameter should be considered a poor predictor of the strength of the Capes Current as nearshore salinities rise appreciably in summer as a result of evaporation (Pattiaratchi *et al.* 1995; Pearce & Pattiaratchi 1999; Pearce *et al.* 2006). Although stronger wind speeds most likely contribute to higher levels of evaporation the relationship between wind speed and salinity was entirely linear (Fig. 5.8). Thus, annual variations in salinity cannot be ruled out in terms of providing some limited information into the annual variability of the strength of the Capes Current.

The complexity of the interactions between the Capes and Leeuwin Currents at the Capes region results in a poor correlation between the strength and productivity of the Capes Current. Generally, the higher the velocity of northward wind the stronger northward flow of the Capes Current and the larger the upwelling at the Capes region. However, the occurrence of the nutrient poor Leeuwin Current in this area influences the productivity of the upwelling. Thus, the productivity of this upwelling is most likely independent of the volume/strength of the annual wind-driven upwelling event.

The wind speeds and to a lesser extent the salinity during the main spawning period of *G. hebraicum* is currently the best estimator of the proximal annual strength of the Capes Current, and was thus used to compare variations in year class strength among the North, Metropolitan and South regions. As this current is generated from the southwest Capes region it is expected to have a higher influence on the southern latitudes of the west coast. In the South and Metropolitan regions, the 1993 to 1996 year classes appeared to have relatively higher numbers of *G. hebraicum* in the age compositions, the corresponding proximal strength of the Capes Current during the spawning period in these four years was the highest estimated for 1994 and 1996 and relatively average for 1993 and 1996. The lowest estimates of the proximal strength of the Capes Current occurred in four out of the five years that preceded 1993, *i.e.* 1988, 1989, 1990 and 1992. Therefore, if recruitment of *G. hebraicum* in the southern regions of the WCB is positively correlated to the strength of the Capes Current, the 1993 to 1996 year classes may appear relatively strong due to the immediate precedence of five average to well below average recruitment years from 1988 to 1992. This suggests that the overall variations in the annual year class strength of *G. hebraicum* are relatively low, which was particularly evident in the age compositions of this species in the North region, and especially evident when compared to other long-lived reef species in the WCB, such as *Pagrus auratus* (see Section 7.0).

6.0 Regional comparisons of the reproductive biology of pink snapper *Pagrus auratus* in the West Coast Bioregion

C. Wakefield, G. Jackson, J. StJohn, I. Keay, and N. Jarvis

Objective 2 To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction

6.1 Introduction

The reproductive biology of *Pagrus auratus* has been extensively studied in New Zealand (*e.g.* Cassie 1956; Crossland 1977a; Crossland 1977b; Scott & Pankhurst 1992; Scott *et al.* 1993) and in eastern and southern Australia (*e.g.* Sumpton 2002; Coutin *et al.* 2003; McGlennon 2004). In Western Australian, until recently, most studies of pink snapper biology had been focussed in the Shark Bay region. Jackson (2007) investigated the reproductive biology of *P. auratus* stocks in the inner gulfs of Shark Bay; while Wakefield (2006) studied the reproductive biology of this species in the oceanic waters off Carnarvon (between 23°30' and 26°30'S), and compared their reproductive characteristics with populations from the Metropolitan (between 31°00' and 33°00'S) and the south coast regions (between 115°30' and 125°00'E). Prior to the study described in this report, as with age and growth of *P. auratus* (Section 7.0), information on the reproductive biology of this species from the main fishing locations in the West Coast Bioregion (WCB) was not available.

Sex inversion has been shown to occur in some juvenile *P. auratus* in the first two years of life, prior to the onset of sexual maturity (Francis & Pankhurst 1988). *Pagrus auratus* have an annual reproductive cycle and are batch spawners that display asynchronous gonadal development and indeterminate fecundity (Scott & Pankhurst 1992). In New Zealand, *P. auratus* spawn from October (mid-spring) through to February (late summer) (Crossland 1977a; Scott & Pankhurst 1992) with an increase in spring water temperatures being the presumed environmental trigger. Spawning in New Zealand has been shown to occur on a daily basis with most spawning occurring in the late afternoon to early evening (Scott *et al.* 1993). In the temperate waters of southern Australia, *P. auratus* spawn in late spring and summer, *i.e.* between September and December on the south coast of Western Australia (Wakefield 2006), and November and January (late spring to mid-summer) in South Australia (McGlennon 2004) and Victoria (Coutin *et al.* 2003). In contrast, the spawning period of *P. auratus* in the more subtropical waters of Australia occurs earlier in the year during winter, *i.e.* May to October in the Shark Bay and Carnarvon regions of Western Australia (Wakefield 2006; Jackson 2007) and May to November in Queensland (Sumpton 2002).

The aims of the research in this Section, which focussed on *P. auratus* in the North, Metropolitan and South regions of the WCB (see Section 2.0) were as follows. 1) Determine the spawning period in each region. 2) Determine the extent to which spawning can be related to water temperature. 3) Estimate the lengths and ages at which females and males attain sexual maturity in each region. 4) Determine the spatial distribution of spawning in the Metropolitan region, with particular focus in the nearshore marine embayment of Cockburn Sound, where annually occurring spawning aggregations of *P. auratus* are known to occur (Wakefield 2006).

6.2 Methods

Details of sample collection and processing are given in Section 2.

6.2.1 Annual reproductive cycle

Seasonal patterns in the reproductive activity of *P. auratus* were investigated using gonadosomatic indices and the sequential development of the male and female gonads.

All *P. auratus* gonads were staged macroscopically using the same staging system as used by Jackson (2007) and Wakefield (2006, Table 6.1).

Mean monthly gonadosomatic indices (GSI) for fish with lengths ≥ the length at which 50% of fish attain sexual maturity (L_{50}, see Section 6.2.2) were calculated as follows,

$$GSI = 100 \times [W_g/((W_f - W_g)]$$

where W_g = wet weight of the gonads and W_f = whole wet weight of the fish.

The peak spawning period of *P. auratus* for each region was defined as the months when the proportion of stages 4 and 5 gonads were greater than 40% for both males and females (see Fig. 6.2). This criterion was used because GSI alone do not necessarily provide a realistic representation of peak spawning activity; rather, the proportion of stage 4 and 5 gonads was chosen as an alternative measure of peak spawning since gonads at these stages will more closely reflect actual spawning activity and hence reproductive output (*e.g.* Fairclough 2005; Wakefield 2006).

Table 6.1. Macroscopic stages of development of *Pagrus auratus*.

Stage	Ovaries	Testis
1 - Immature	Clear string- like threads	Clear string- like threads
2 - Resting / regressed	Occupy up to one half of the length of ventral cavity. Cylindrical and pink to orange.	Occupy up to one half of ventral cavity. Flat or ribbon-like and white
3 - Developing	Occupy up to two thirds of ventral cavity and orange. Blood capillaries and eggs visible.	Occupy up to two thirds of ventral cavity and white. Posterior end has a more 'swollen' appearance than at stage 2.
4 - Developed	Occupy up to full length of ventral cavity. Yolked eggs clearly visible but not hydrated. Blood capillaries more conspicuous.	Testis much larger occupying up to full length of ventral cavity. No milt discharged when slight pressure is applied to lobes or abdomen.
5 - Spawning	Similar in size to stage 4. Hydrated oocytes visible throughout ovarian lobes or concentrated in oviduct.	Similar to stage 4 in size. Milt discharged when slight pressure is applied to lobes or abdomen.
6 - Spent	Ovaries reduced in size, flaccid and red in areas.	Testis reduced in size, flaccid and red in areas.

6.2.2 Length and age at maturity

Length and age at maturity were estimated for *P. auratus* based on the macroscopically stage gonads of fish collected during the peak spawning period for each region: July to September for North region, August to January for Metropolitan region and December and January for the South region.

The lengths at which 50% of female and male *P. auratus* attained sexual maturity (L_{50}), in each region were determined using logistic regression analysis to determine the relationship with length, of the probability that a fish during the spawning period possessed gonads at stages III to VI. Note that, during the spawning period, fish with gonads of these stages would have had the potential to spawn, were spawning or had recently spawned and that fish with gonads at stages I and II would have remained immature. The relationship used, *i.e.*

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

was a reparameterised form of the logistic equation, where P_L = the proportion of mature *P. auratus* at a particular length L, and the L_{50} and L_{95} = the estimated lengths at which 50% and 95% of *P. auratus* have attained sexual maturity, respectively. Values of the L_{50} and L_{95} and their 95% confidence intervals were determined by bootstrapping, where estimates were obtained from the analysis of data sets produced by random resampling, with replacement, of each data assemblage to generate 2000 estimates of the parameters of the logistic equation. The parameters and 95% confidence intervals for the reparameterised logistic equation were calculated as the median and upper and lower 2.5 percentiles of the 2000 bootstrap estimates of each length class.

As there was insufficient data to obtain reliable estimates of L_{50} and L_{95} for *P. auratus* in the South region, the estimates of these parameters estimated for fish from the Metropolitan region were assigned to those for the South region. Estimates of sexual maturity with respect to age were calculated using the same equation, but with A_{50} and A_{95} substituted for L_{50} and L_{95}, respectively.

6.3 Results

6.3.1 Annual reproductive cycles

The ovaries of female *P. auratus* with lengths greater then or equal to the L_{50} at maturity in the North region were exclusively stage 1-2, *i.e.* immature or resting, in April only (Fig. 6.1). During May and June some *P. auratus* possessed ovaries at stages 3 or 4, *i.e.* developing or developed. Fish containing ovaries with hydrated oocytes (stage 5) were present in the months from July to November and a few individuals in February. The prevalence of female *P. auratus* with spent ovaries (stage 6) increased progressively from July to March (Fig. 6.1).

In the Metropolitan region, *P. auratus* with lengths greater than or equal to the L_{50} at maturity possessed exclusively or almost entirely ovaries at stage 1-2 in each month between March and July (Fig. 6.1). *P. auratus* with ovaries at stage 5 were caught predominantly between October and January and those with spent ovaries were found only between November and February (Fig. 6.1).

In the South region, *P. auratus* with lengths greater than or equal to the L_{50} at maturity were exclusively, almost entirely or most likely at stage 1-2 in each month from April to September (Fig. 6.1). Fish with ovaries that were developing, developed or contained hydrated oocytes (stages 3 to 5) were caught between October and January. *P. auratus* with spent ovaries were caught predominantly from January to March (Fig. 6.1). The trends exhibited by the macroscopically staged ovaries of *P. auratus* from the South region need to be treated cautiously given the low or zero sample sizes for most months.

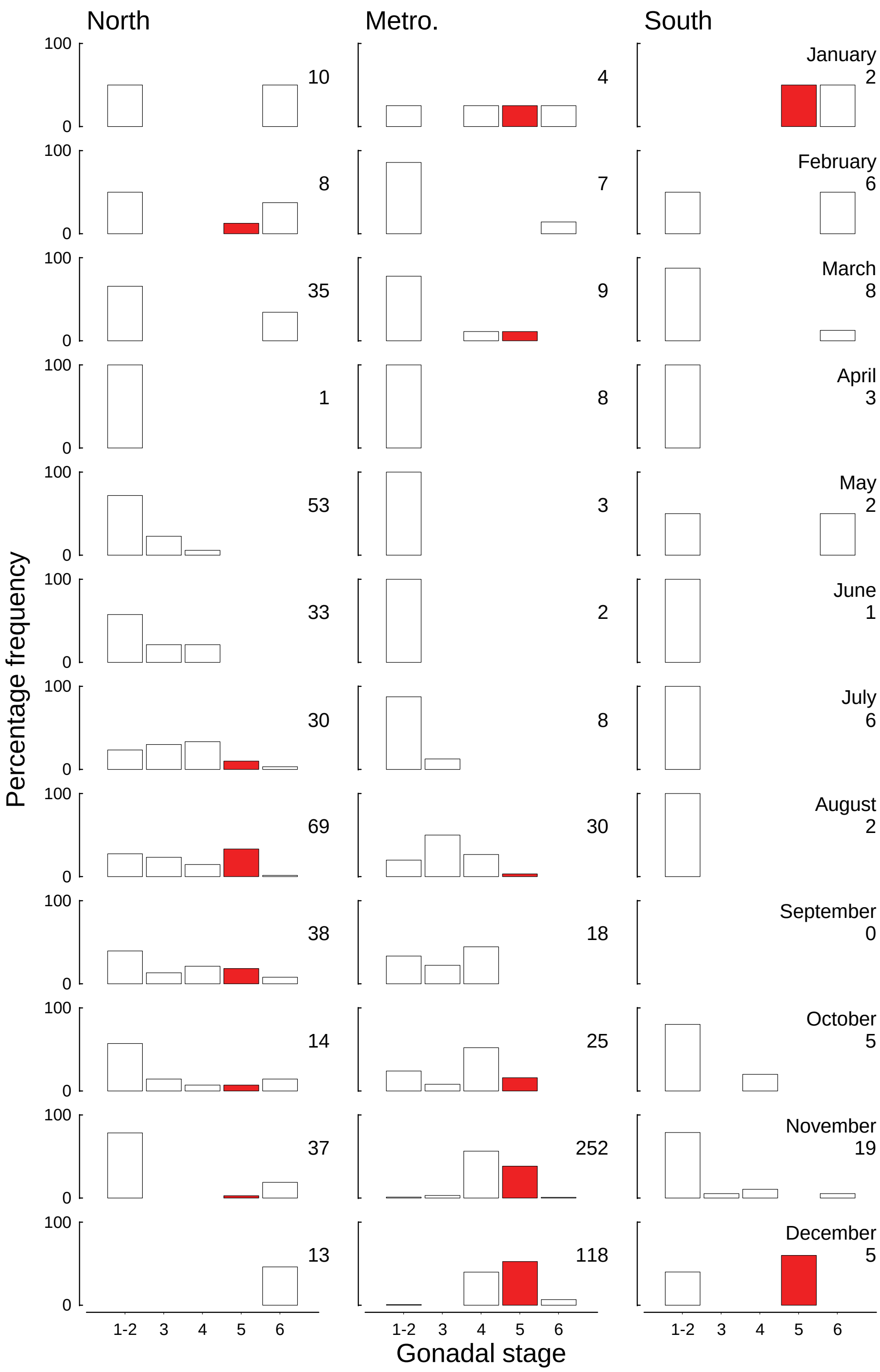

Figure 6.1. Percentage frequency of the occurrence of *Pagrus auratus* with ovaries at the different stages in development in samples obtained from the North, Metropolitan (from Wakefield 2006) and South regions. Data are derived from fish ≥ L_{50} at maturity for the North and Metropolitan regions, the L_{50} from the Metropolitan region was used for the South region (see Fig. 6.3). Red bars represent ovaries containing hydrated oocytes (stage 5).

The mean monthly GSIs for female *P. auratus* in the North region increased progressively from 0.28 in March to a peak of 1.86 in July and then declined to less than 0.28 from November to January, before a slight increase to 0.76 in February (Fig. 6.2). The mean monthly GSIs for males followed a similar trend (Fig. 6.2). The prevalence of females and males with gonads that were developed (stage 4) or spawning (stage 5) in the North region was greater than 50% in each month from July to September, *i.e.* mid-winter to early spring (Fig. 6.2).

The trends exhibited by the mean monthly GSIs of female and male *P. auratus* in the Metropolitan region differed from that in the North region. The mean monthly GSIs for females displayed an increase slightly later than that in the North region, beginning in July at 0.6 and increasing to 3.2 in November, before a precipitous decline to less than 0.95 in the months from February to June (Fig. 6.2). Note, the peak in mean monthly GSIs for females from the Metropolitan region was slightly less than twice that of the North region. As in the North region, the trends in mean monthly GSIs for males were very similar to those of females for the Metropolitan region (Fig. 6.2). The monthly spawning prevalence of *P. auratus* with gonads at stages 4 and 5 collectively, from the Metropolitan region was greater than 50% in each month from approximately August to January, *i.e.* late winter to mid summer (Fig. 6.2).

The trends in mean monthly GSIs for both females and males from the South region were irregular, which was most likely due to the small sample sizes for each month (Fig. 6.2). However, the highest values of mean monthly GSIs for female *P. auratus* from the South region were recorded in October, December and January. These months also coincided with the highest prevalence of females with ovaries at stages 4 and 5 combined, *i.e.* greater than 20% (Fig. 6.2). The spawning of male and female *P. auratus* from the South region predominantly occurred from October to January.

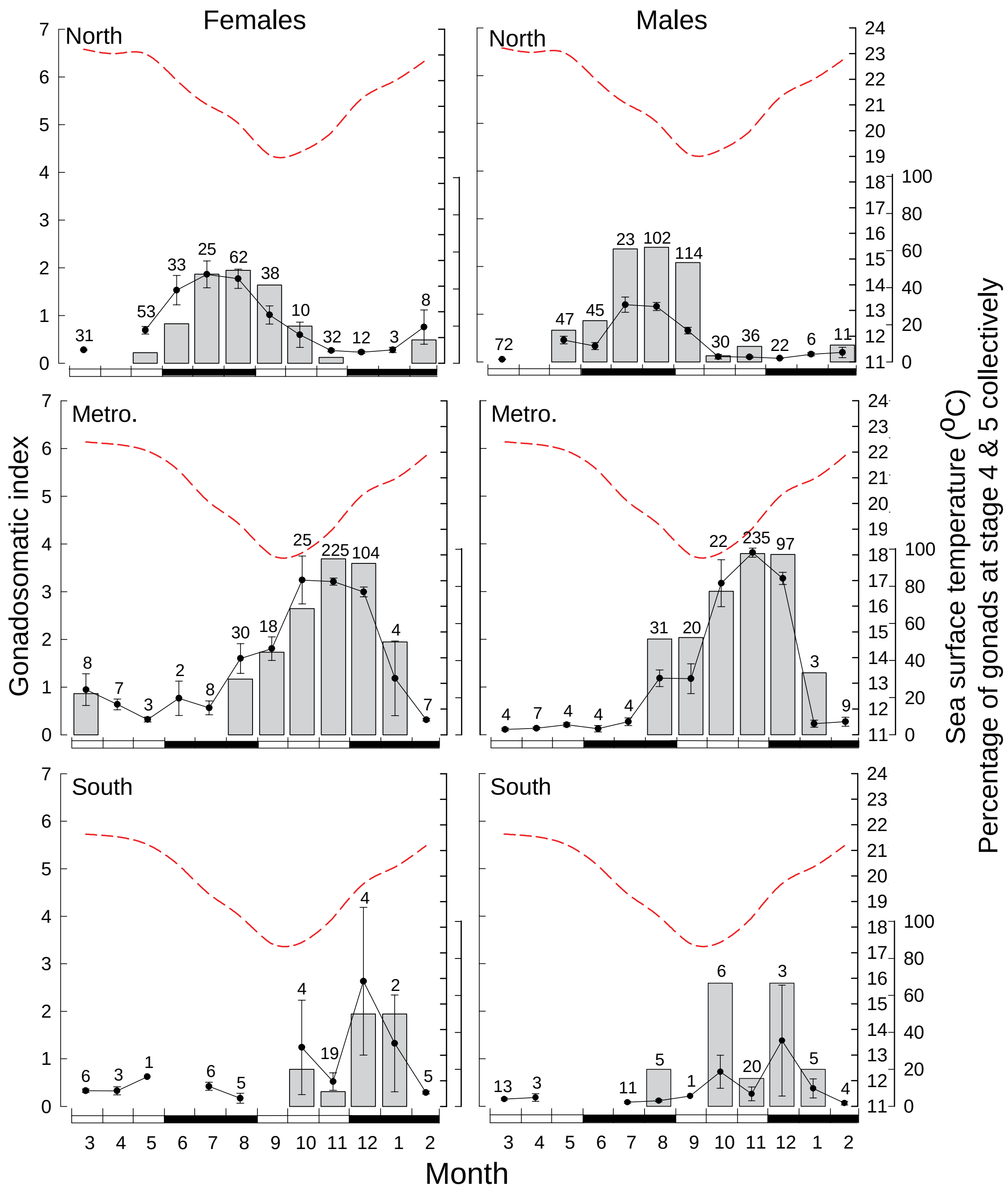

Figure 6.2. Mean monthly gonadosomatic indices (±1 SE, solid lines, sample sizes above) and percentage of macroscopic stages 4 and 5 combined (grey bars) for females (left) and males (right) of *Pagrus auratus* ≥ L_{50} at maturity (L_{50} from Metropolitan region used for the South region, see Fig. 6.3) and corresponding mean monthly sea surface temperatures (°C, dashed lines) from the North, Metropolitan (from Wakefield 2006) and South regions. On the x-axis, open rectangles represent autumn and spring months and closed rectangles the winter and summer months.

6.3.2 Relationship between spawning and water temperature

Mean monthly sea surface temperatures in the North region were at their maximum of *ca* 23°C in each month from February to May, before gradually declining to their minimum of 19.1°C in September, and then gradually increased through October to January (Fig. 6.2). The annual trend in mean monthly sea surface temperatures was similar but displayed lower values in corresponding months with increasing latitude for the Metropolitan and South regions. The differences in the maximum temperatures for the Metropolitan and South regions were approximately one and two degrees Celsius lower, respectively, than the North region (Fig. 6.2). The lowest mean monthly sea surface temperatures for the Metropolitan and South regions occurred in the same month as the North region, *i.e.* September, but were lower at 18.0 and 17.4°C, respectively.

It should be noted that the sea surface temperatures used in this study were not taken at the locations of spawning of *P. auratus* in each region and thus may not reflect a direct relationship between water temperature and spawning, but however do give an indication of seasonal correlations. In the North region, the prevalence of female and male *P. auratus* with developed or spawning gonads was highest (> 50 %) in each month from July to September. The corresponding mean monthly sea surface temperatures for this period were 21.1°C in July and decreased to their minimum of 19.1°C in September (Fig. 6.2). Thus, the majority of spawning of *P. auratus* in the North region occurred during when water temperatures were declining and at their minimum.

In contrast to the situation in the North region, the prevalence of stage 4 and 5 gonads of female and male *P. auratus* was highest when water temperatures were at and increasing from their minimum in both the Metropolitan and South regions (Fig. 6.2). In the Metropolitan region the main spawning period, *i.e.* August to January, coincided with water temperatures of 19.2 to 21°C, respectively. In the South region spawning occurred predominantly between October and January when water temperatures were 17.4 to 20.3°C, respectively.

Therefore, although the spawning periods of *P. auratus* occurred at different times of the year among regions, the majority of spawning of *P. auratus* along the lower west coast of Western Australia coincided with similar water temperatures that were within a narrow range of approximately 3.5°C.

6.3.3 Length and age at maturity

Estimates of the length and age at which *P. auratus* attains maturity were derived from data from the months that corresponded to the spawning period in the North and Metropolitan regions, *i.e.* May to November in the North region and August to December in the Metropolitan region. There were insufficient numbers of female and male *P. auratus* collected from the South region to adequately estimate the length and age at maturity. The estimated total length at which 50% of female *P. auratus* attained maturity (L_{50}) in the North region was slightly higher than that of males, *i.e.* 487 and 426 mm, respectively (Table 6.2). The L_{50} for female *P. auratus* was also larger than that for males in the Metropolitan region, *i.e.* 585 and 566 mm, respectively (Table 6.2). The L_{50}s for the Metropolitan region were larger than that for the North region. This was not the case for the estimates of the age at which 50% of *P. auratus* attained maturity (A_{50}), which were similar for females and males from both regions, *i.e.* 5.5 to 5.7 years, with the exception of females from the North region (3.7 years, Table 6.2). It should be noted that small sample sizes of *P. auratus* greater than 700 mm TL and nine years of age for females and males from the North region might have reduced the accuracy in the estimates of L_{50} and A_{50} (Figs 6.3 & 6.4).

Table 6.2. Summary of the lengths and ages at which 50% and 95% (L_{50}, L_{95}, A_{50} and A_{95} respectively) of male and female *Pagrus auratus* reach sexual maturity, as well as the minimum length and age of mature fish (L_{min} and A_{min}, respectively) for the North, Metropolitan and South regions.

	L_{min} (mm, TL)	L_{50} (mm, TL)	L_{95} (mm, TL)	*n*	A_{min} (yr)	A_{50} (yr)	A_{95} (yr)	*n*
North								
Female								
Estimate	405	487	682	292	3.7	5.5	11.1	192
Upper		506	757			6.2	16.5	
Lower		469	625			4.9	8.9	
Male								
Estimate	319	426	629	311	2.2	3.8	9.3	199
Upper		446	707			4.5	12.5	
Lower		400	576			2.4	7.6	
Metro								
Female								
Estimate	375	585	752	708	2.8	5.7	8.0	588
Upper		602	784			5.9	8.6	
Lower		567	720			5.5	7.5	
Male								
Estimate	407	566	730	661	2.9	5.6	8.5	561
Upper		583	756			5.8	9.1	
Lower		546	691			5.3	8.0	
South								
Female								
Estimate	457	Insufficient		181	4.1	Insufficient		140
Upper		data				data		
Lower								
Male								
Estimate	429	Insufficient		197	3.2	Insufficient		158
Upper		data				data		
Lower								

TL, total length; yr, years; n, sample size.

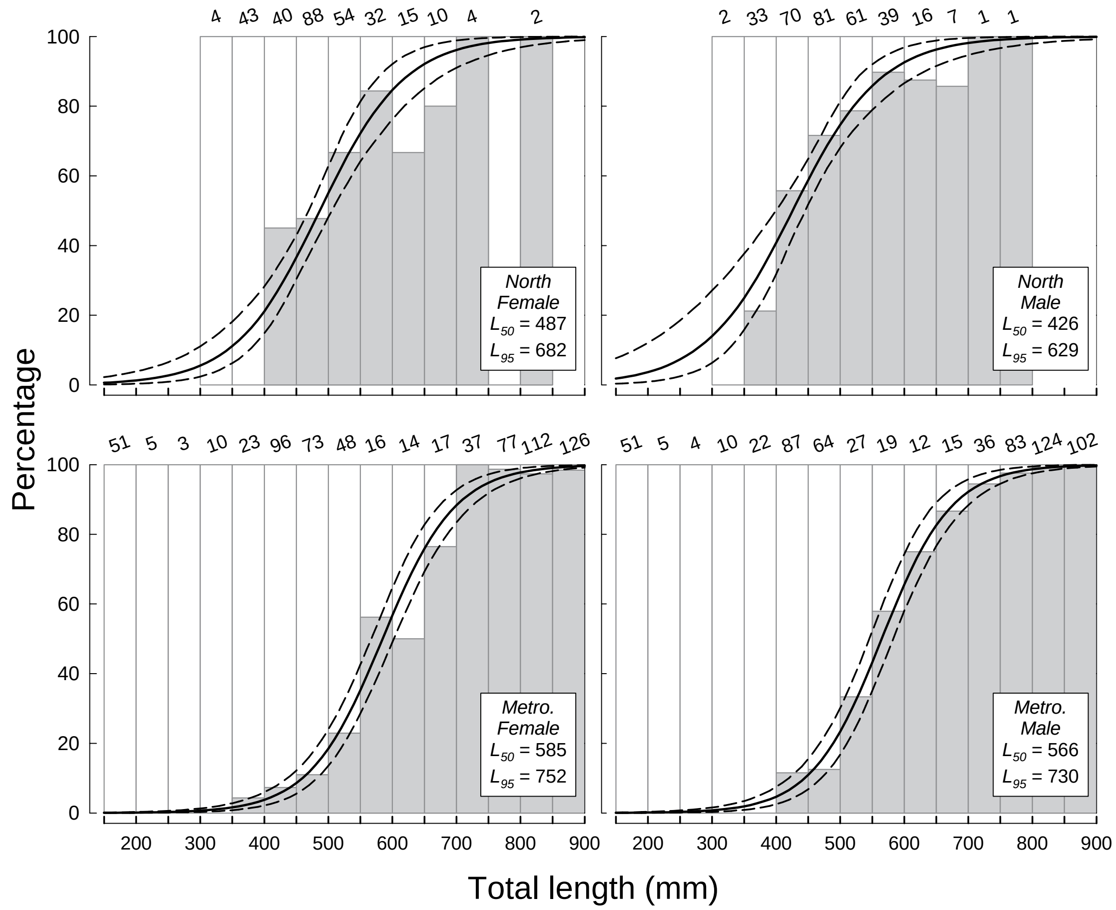

Figure 6.3. Percentage frequency of gonads of immature (stages 1-2, white bars) and mature (stages 3-6, grey bars) *Pagrus auratus* in sequential 50 mm length classes (sample sizes above) of females (left) and males (right) from the North (above) and Metropolitan (below, from Wakefield 2006) regions. Lines represent the expected percentage of mature individuals and 95% CIs as determined from logistic regression analysis.

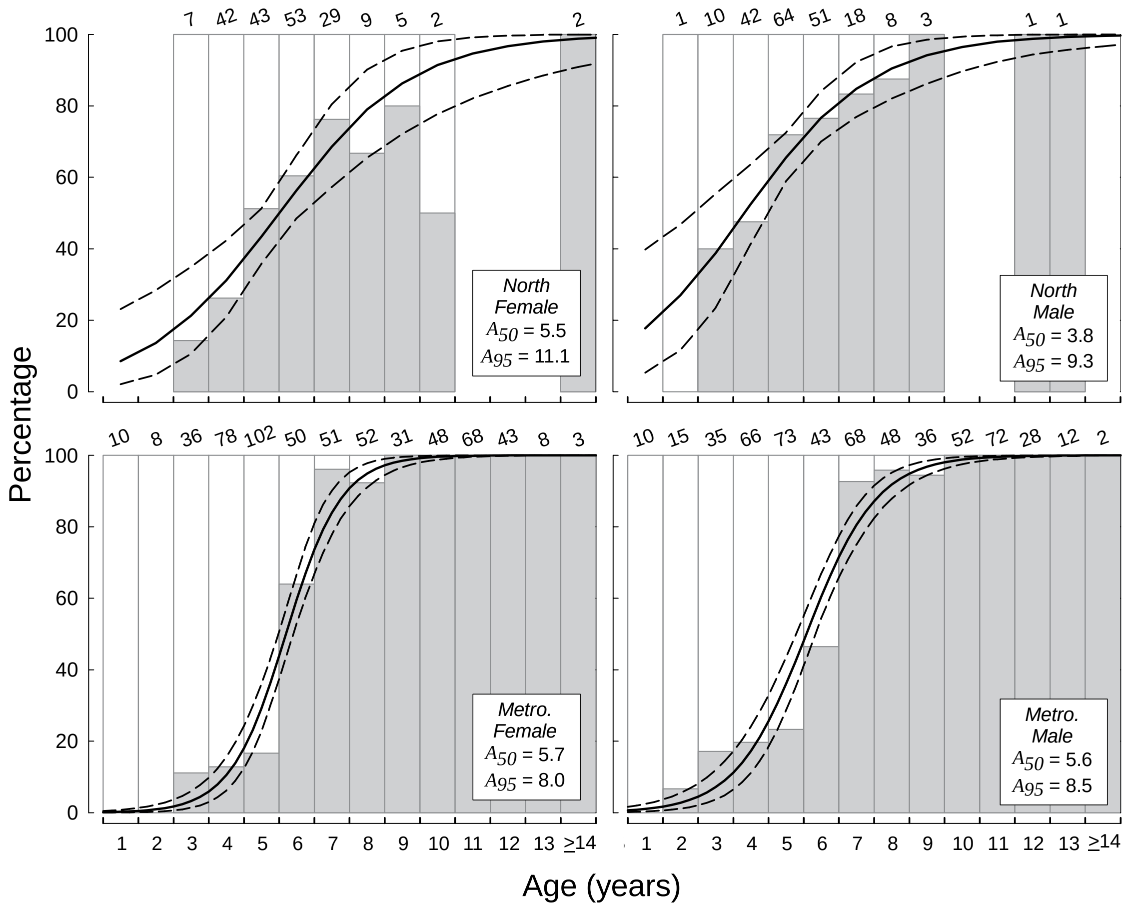

Figure 6.4. Percentage frequency of gonads of immature (stages 1-2, white bars) and mature (stages 3-6, grey bars) *Pagrus auratus* in each age class (sample sizes above) of females (left) and males (right) from the North (above) and Metropolitan (below, from Wakefield 2006) regions. Lines represent the expected percentage of mature individuals and 95% CIs as determined from logistic regression analysis.

6.3.4 Spatial distribution of spawning in the Metropolitan region

There was a marked contrast in the length distributions of *P. auratus* during the main spawning period, *i.e.* October to December, in the Metropolitan region, between outside and inside the nearshore marine embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound, which are locations where this species is known to aggregate annually to spawn (Wakefield 2006). During this period a large majority of *P. auratus* ≥ L_{50} at maturity (*ca* 585 mm TL) were found inside these embayments (*ca* 95%, Fig. 6.5), with 99.6% of these fish possessing mature gonads, *i.e.* stages 3 to 6 (Table 7.2). In contrast very few *P. auratus* ≥ L_{50} at maturity were caught outside of these embayments during this period (*ca* 5%, Fig. 6.5), and of these few fish only 65.5% possessed mature gonads (Table 6.3). A large portion of fish < the L_{50} at maturity were found outside these embayments during the spawning period (*ca* 91%), with 92.8% of these fish possessing immature gonads (Table 6.3). This highlights the importance of the nearshore marine embayments as a location for spawning of *P. auratus* in the Metropolitan region. This spatial distinction in mature fish during the spawning period was not witnessed in the North or South regions.

Table 6.3. Numbers of *Pagrus auratus* caught outside and inside the nearshore marine embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound in the Metropolitan region, with respect to the corresponding L_{50} at maturity (Table 6.2) and gonadal development, *i.e.* immature (stages 1-2) or mature (stages 3-6). The proportions of each of these criteria are displayed as a spawning frequency (%).

	Outside		**Inside**	
	$< L_{50}$	$\geq L_{50}$	$< L_{50}$	$\geq L_{50}$
Stages 1 - 2	258	10	18	3
Stages 3 - 6	20	19	9	736
Total	278	29	27	739
Spawning frequency	7.2%	65.5%	33.3%	99.6%

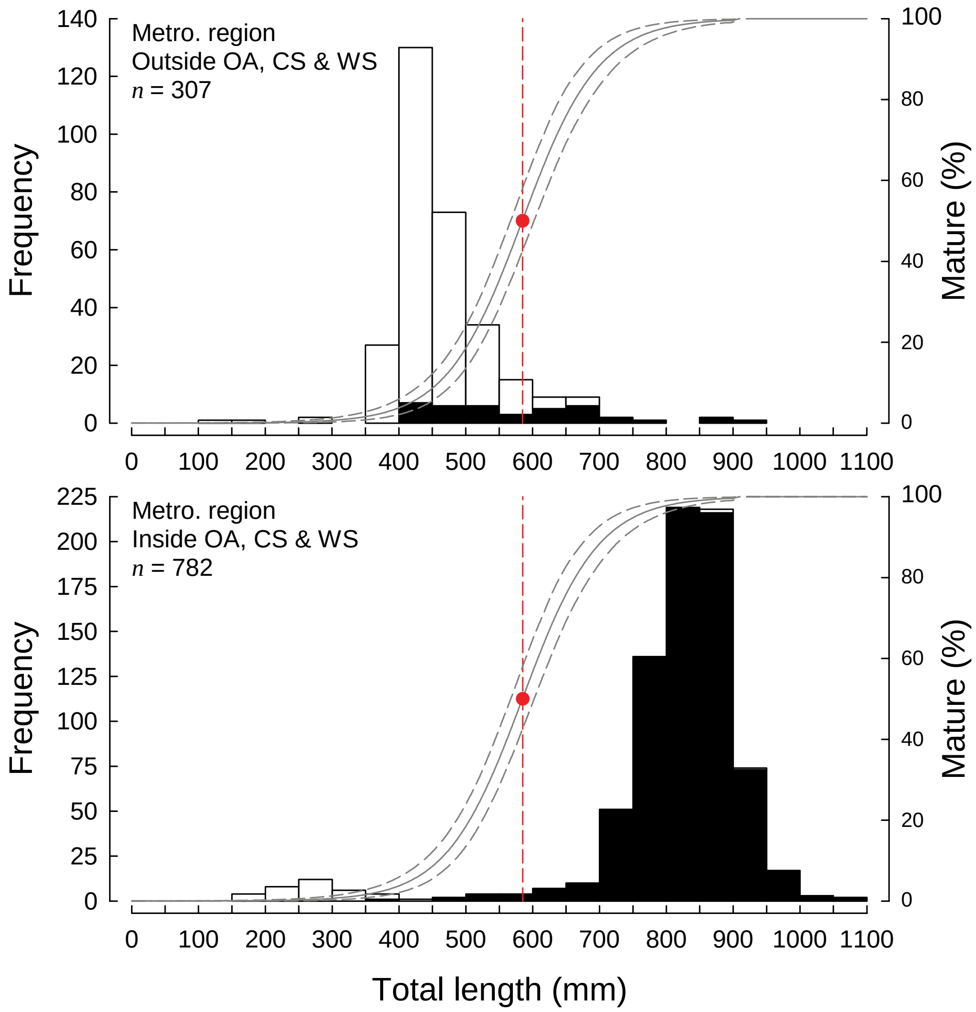

Figure 6.5. Frequency histograms of gonads of immature (stages 1-2, white bars) and mature (stages 3-6, black bars) *Pagrus auratus* from the Metropolitan region in sequential 50 mm TL classes caught outside (above) and inside (below) the nearshore marine embayments of Owen Anchorage (OA), Cockburn Sound (CS) and Warnbro Sound (WS) during the spawning period, *i.e.* October to December (Wakefield 2006). The logistic regressions (grey lines) represent the expected percentage of mature females and 95% CIs for the Metropolitan region (from Fig. 6.3). The dashed red line represents the L_{50} at maturity for females in the Metropolitan region (see Table 6.2).

6.4 Discussion

The timing and duration of the spawning period of *Pagrus auratus* differed markedly among the North, Metropolitan and South regions. The spawning period occurred earlier and was most protracted at the lowest latitudes in the North region, where fish were caught with developing (stage 3) through to recovering (stage 6) gonads for eleven months of the year from May to March. However, the highest prevalence of spawning (gonads at stages 4 and 5 collectively were > 50%) occurred over three months between mid-winter and early-spring from July to September. In contrast, the spawning period of *P. auratus* occurred later and was least protracted at the highest latitudes in the South region, with spawning predominantly occurring for four months between mid-spring and mid-summer from October to January. In the mid latitudes of its range in Western Australia, *i.e.* the Metropolitan region, individuals of this species were found to possess developed gonads over six months from August to January. However, the majority of spawning in this region occurred over three months between mid-spring and earl-summer from October to December.

The mean monthly sea surface temperatures in the North region during the period when spawning of *P. auratus* was most prevalent (> 50% of fish with stage 4 and 5 gonads collectively), *i.e.* July to September, lay between 21.1 and 19.1°C, respectively. Furthermore, those temperatures during the most prevalent months of spawning of this species in the Metropolitan region were very similar to the North region, *i.e.* 19.2 to 21.0°C between August and January, respectively. Due to small sample sizes, the spawning period of *P. auratus* in the South region was not accurately described. Nonetheless, the months in which the GSIs and percentage of fish with gonads at stages 4 and 5 collectively were the highest, *i.e.* October, December and January, also coincided with similar mean monthly sea surface temperatures to that of the North and Metropolitan regions, *i.e.* 17.4 to 20.3°C. In addition, the mean monthly water temperatures during the months with the highest prevalence of spawning of *P. auratus* in the Carnarvon region (located north of the WCB) and south coast of Western Australia were also within this narrow range between ca 19 to 21°C (Wakefield 2006). Thus, there is overwhelming evidence that a strong relationship between spawning and water temperature exists for *P. auratus* along the west and south coast of Western Australia. Furthermore, the peak period for reproduction of this species occurs within a specifically narrow water temperature range, regardless of whether temperature regimes are decreasing from their summer maxima in the northern sub-tropical regions or increasing from their winter minima in the southern temperate regions. Given spawning of *P. auratus* is strongly correlated to water temperature, the fact that gonads of females and males were found at stages 3 to 6 (developing to recovering) for eleven months of the year in the North region, may have been confounded by pooling samples monthly over a wide area of coastline, as spawning most likely occurred earlier in the northern and/or later in the southern areas of this region.

A large majority of spawning in the Metropolitan region was isolated in the nearshore marine embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound (see also Wakefield 2006). This was evident from the spatial distinction between inside and outside of these nearshore marine embayments in the numbers of fish ≥ L_{50} during the respective spawning period that also possessed developing, developed or recovering gonads (stages 3 to 6). The hydrodynamics associated with these embayments during late-spring and early-summer (Gersbach 1993; Apai 2001; Doak 2004) results in the retention of eggs and larvae of *P. auratus* in each of these areas (Wakefield 2006; Doak 2004). Although *P. auratus* were caught with gonads in spawning condition (stages 3 to 6), during their respective spawning periods in the North and South regions, the spatial distinction of mature fish described in the

Metropolitan region was not apparent for these two regions. This is most likely due to the absence of such embayments in the North and South regions. This aggregation of spawning of *P. auratus* in the nearshore embayments of the Metropolitan region was also reflected in the respective age and length compositions for these areas (see Fig. 6.5), where older and larger (≥ L_{50}) *P. auratus* were more abundant inside the nearshore embayments in the Metropolitan region, than the waters outside of these embayments in the Metropolitan region and the entire North and South regions.

Juvenile *P. auratus* were identified to occur within Cockburn Sound for the first 14 months of their life from monthly trawl surveys in 1971/72 (Lenanton 1974). Furthermore, Owen Anchorage, Cockburn Sound and Warnbro Sound were identified as important nursery/ recruitment areas for the Metropolitan region as *P. auratus* < 18 months of age were not found outside of these nearshore marine embayments in that region (Wakefield 2006). In South Australia and Victoria, studies of the age-related elemental concentrations of the otoliths found adult *P. auratus* collected from a wide area of coastline (> 2000 km in South Australia and *ca* 550 km in Victoria) originated from one or two nearshore marine embayments (Fowler *et al.* 2005; Hamer *et al.* 2005). Given the relative paucity of nearshore marine embayments in the West Coast Bioregion and their importance to *P. auratus* in South Australia and Victoria, the extent to which juvenile *P. auratus* recruits from Owen Anchorage, Cockburn Sound and Warnbro Sound move along the west coast of Western Australia, thereby contributing to pink snapper populations far from these nursery areas may be substantial, and therefore requires further investigation.

7.0 Regional comparisons of the age and growth of *Pagrus auratus* in the West Coast Bioregion

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Objective 2 To determine whether there are regional differences in the biology of dhufish and pink snapper populations along the West Coast, particularly in age, growth and reproduction

7.1 Introduction

Age and growth of *P. auratus* has been extensively studied in New Zealand (*e.g.* Francis *et al.* 1992; Paul 1992) and in eastern and southern Australia (Ferrell *et al.* 1992; McGlennon *et al.* 2000; Sumpton 2002; Ferrell 2004; Fowler *et al.* 2004). In Western Australian, until recently, age and growth in the species had only been studied in detail in the Shark Bay region, based on fish taken by the commercial fishery in oceanic waters outside Shark Bay (Moran *et al.* 2005) and from the recreational fishery in the inner gulfs (Jackson 2007). Wakefield (2006) investigated age and growth in *P. auratus* from the oceanic waters off Carnarvon (between 23°30' and 26°30'S) in more detail, and compared the growth characteristics with those of *P. auratus* from the Metropolitan region (between 31°00' and 33°00'S) and the south coast (between 115°30' and 125°00'E). Prior to the study described in this report, as with their reproductive biology, information on age and growth of this species from the main fishing locations in the West Coast Bioregion (WCB) was not available.

The interpretation of annuli in sectioned sagittal otoliths is now routinely used for ageing *P. auratus* in New Zealand and Australia (Francis *et al.* 1992; McGlennon *et al.* 2000; Coutin *et al.* 2003; Fowler *et al.* 2004; Moran *et al.* 2005). Annulus formation has been validated as annual for fish up to 30+ years in Australia and New Zealand (Ferrell *et al.* 1992; Francis *et al.* 1992; Fowler *et al.* 2004; Wakefield 2006; Jackson 2007).

The aims of the research in this Section were to compare size and age structure, and growth characteristics of *P. auratus* in the North, Metropolitan (inside and outside of Cockburn Sound) and South regions of the WCB (see Section 2.0)

7.2 Methods

Details of sample collection and otolith preparation are given in Section 2.0.

7.2.1 Otolith interpretation

The *P. auratus* otolith sections were examined microscopically under reflected light against a black background as described by Jackson (2007). Opaque zones were counted along a common axis from the primordium to the proximal edge (Fig. 7.1).

A total of four, experienced otolith readers were involved with the interpretation of the sections. Otoliths from the North and South regions plus a small number from the Metropolitan region (but excluding all those from Cockburn Sound) were read once by one of either of three readers (mostly by JN and GJ, smaller number by BR). A fourth reader (CW) read all the otoliths from the Metropolitan region only (including all the Cockburn

Sound fish). For each otolith, the number of completed opaque zones and a classification of the outer margin of the otolith were recorded (Table 7.1).

The sections that were read by both JN and GJ were used to investigate bias and precision. Bias in opaque zone counts was examined using the age frequency table and age bias graph method (Campana *et al.* 1995, based on ‘counts’ rather than ‘age’). Between reader precision was calculated as an index of average percentage error (IAPE, Campana *et al.* 1995 *sensu* Beamish and Fournier 1981).

The opaque zone counts recorded by the different readers were compared and either accepted or rejected based on the following protocols:

- No difference in opaque zone counts -> accept count;
- If counts differed by ‘1’, <u>either</u> look at otolith margin (*e.g.* if one reader counted ‘3’ with opaque edge and other counted ‘4’ with translucent edge-> accept as ‘4’ with translucent edge) <u>or</u> use count/edge type from both readers alternatively;
- If counts differed by ‘2’, take mean count;
- If counts differed by >’2’, look at fork length and take most appropriate count etc. If could not decide, reject sample (but checked fish length to ensure not just rejecting larger/older fish).

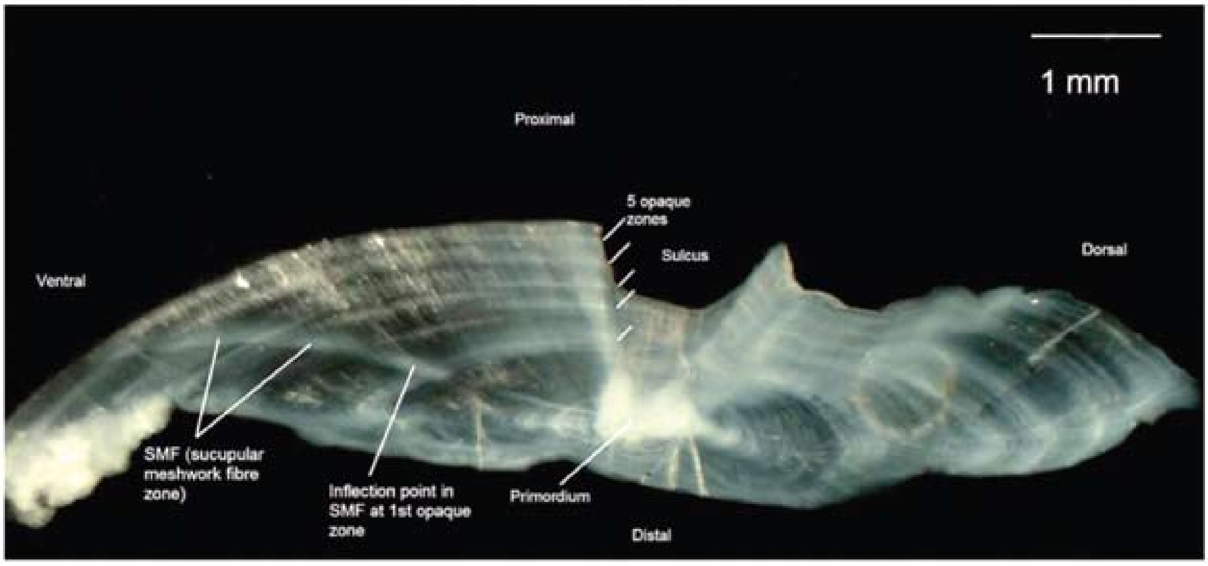

Figure 7.1. Image of a transverse section of a *Pagrus auratus* otolith under reflected light showing the primordium, sulcus and inflection point in the subcupular meshwork fibre zone that is typically used to locate the first opaque zone.

Table 7.1. Classification of outer margin of otolith sections of *Pagrus auratus*.

Category	Otolith margin appearance
Opaque	Opaque margin
Thin translucent	Translucent margin is less than 50% developed as compared to the previous translucent zone
Wide translucent	Translucent margin is 50% or more developed as compared to the previous translucent zone

7.2.2 Validation of annual formation of opaque zones on otoliths

Marginal increment analysis was used to determine whether the opaque zones in the sectioned otoliths of fish from the Metropolitan region were formed annually and to identify when they became delineated (Wakefield 2006). The marginal increment is the distance to the edge of the otolith from the outer margin of the outermost opaque zone that is delineated from the edge of the otolith through the presence of a new translucent zone. Note however, that it also includes any opaque material that is being deposited at the edge of the otolith and which, through the formation of a new translucent zone on its outer edge will become the next opaque zone. When a single opaque zone was present and delineated from the otolith's edge, the marginal increment is expressed as a proportion of the distance between the primordium to the outermost edge of the single opaque zone. When two or more opaque zones were present, and the outermost of those two zones are delineated from the otolith's edge, the marginal increment is expressed as a proportion of the distance between the outer edges of the two most recently delineated opaque zones on the otolith. All measurements were made along the same axis and perpendicular to a line between the primordium and the otolith edge and as close to the sulcus acusticus on the ventral side as possible (see Fig. 7.1). The measurements were taken by capturing images of the sectioned otoliths using a video camera (Leica DC300) attached to the microscope, which were analysed on a computer using imaging software (Leica IM1000). Each otolith section was categorised as having either a translucent or opaque outer margin.

The marginal increment values for otoliths with different numbers of opaque zones throughout the year were analysed separately for fish from each geographical region. Values for the marginal increments were pooled by calendar month and fitted with the logistic equation $C_t = C_{max} / [\ 1 + e^{-(a + bt)}]$, where C_t = the marginal increment value at time t (days), C_{max} = the average maximum marginal increment value and a and b = constant coefficients. Note that, as there were two very distinct distributions in the marginal increments in some months, the data for the distribution with the greater marginal increment values in each of those months when both cohorts were present were assigned values of t that were 365 days greater than those of the distribution with the smaller marginal increment values.

7.2.3 Age determination

The algorithm used to convert opaque zone counts to individual age varied among regions because the timing of spawning varied throughout the bioregion (see Section 6.0). Examination of otolith margins in *P. auratus* showed that opaque zones were delineated and the annulus formed between July and December for *P. auratus*. This period coincided with the onset of reproductive maturity and spawning activity. The generalized birth date was established as 1 July for the North region and 1 December for the Metropolitan and South regions (Wakefield 2006). Thus, the age of each *P. auratus* on its date of capture in each region was estimated using a combination of the birth date, the time of year when the opaque zones on the otoliths of the majority of *P. auratus* become delineated in that region, the time of formation of the first opaque zone and the number of opaque zones.

7.2.4 Growth

A von Bertalanffy growth equation was used to model the growth of *P. auratus* from the North, Metropolitan and South regions. von Bertalanffy growth curves and parameters were compared (i) between males and females within each region and (ii) for both sexes among the three regions using a likelihood-ratio test (Kimura 1980) under the assumption that residual variances differed (Cerrato 1990).

7.3 Results

7.3.1 Contributions of samples from each sector

A total of 4,090 *P. auratus* were collected between January 2002 and December 2005 for this study (Table 7.2). The proportional contribution of these samples by the different fishing sectors varied amongst the three regions, reflecting both sampling biases and real regional differences in fishing activity. In the North region, 91% of the samples came from the commercial sector compared with less than 4% from the recreational sector. In contrast, in both the Metropolitan and South regions, around 44% of the samples were from commercial catches, around 15% from research sampling and the remainder (*ca* 41%) from the recreational sector including charter, recreational fishers and fishing club tournaments.

Table 7.2. Number of *Pagrus auratus* collected by sampling region, sector and year.

Region	Sector	Year				%
		2002	2003	2004	2005	
North	Commercial	5	680	519	579	91
	Recreational	1	3		68	4
	Research		69		35	5
	Total	**6**	**752**	**519**	**682**	**1959**
Metropolitan	Commercial	444	297	29		44
	Recreational					
	Fishing club		23	93	125	14
	Fishing charter			303	23	19
	Other	4	42	48	49	8
	Research	12	85	115	57	15
	Total	**460**	**447**	**588**	**254**	**1749**
South	Commercial			106	64	45
	Recreational	10	16	26	104	41
	Research		32		24	15
	Total	10	48	132	192	382
Grand total		**476**	**1247**	**1239**	**1128**	**4090**

7.3.2 Bias and precision

Otoliths were examined from a total of 2,533 fish. Of these, n = 1,541 (mostly from the South and North regions) were read once by the primary readers (JN and GJ), and the count data used to investigate bias and between reader precision. The differences in opaque zone counts for these sections were as follows: nil difference = 39%, difference of ‘1’ = 43%, Difference of ‘2’ = 14% and difference of > 2 = 4%.

The number of opaque zones counted ranged from 2 to 32. No significant bias was evident for sections read by both JN and GJ (Figs 7.2 & 7.3). The level of precision between the two independent readers for sections read by both was reasonable with an IAPE score calculated at 7.7%. For the snapper aged in this study, protocols for ageing fish developed at a national level as best practise standards were applied. The differences between the two readers that still occurred reflect the fact that for otoliths with poor readability there is no way of ascertaining which reader is right and which is wrong in terms of the true age of the fish; indeed, neither could be “exactly” right. While the IAPE score for snapper in this study is higher than the 5% upper-threshold expected in some fish-ageing laboratories for fish of moderate longevity (Campana 2001), we contend that this score is acceptable for fish whose otoliths are difficult to read.

Table 7.3. Age frequency table summarising pairwise comparisons of opaque zone counts in *Pagrus auratus* otoliths (n = 1,541) between the two primary readers (JN and GJ).

Opaque zone counts from Reader 1	Opaque zone counts from Reader 2																								
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
0	21	11																							32
1		28	2	2																					32
2			30	37	25	4			1																97
3			19	176	153	53	8	1																	410
4				65	175	153	62	8	4																467
5				11	55	102	83	33	5	1		1													291
6					10	26	43	24	8	3		1													115
7					1	6	8	17	8	1	2														43
8						1		3	5	2	2	2													15
9									1	3	1	1		1		1									8
10								1			2	2													5
11										1	4	4	3												12
12													2	1											3
13															1										1
14																									0
15									1			1			1										3
16																		1							1
17																	1								1
18																						1			1
19																									0
20																				1		1			2
21																									0
22																			1						1
23																									0

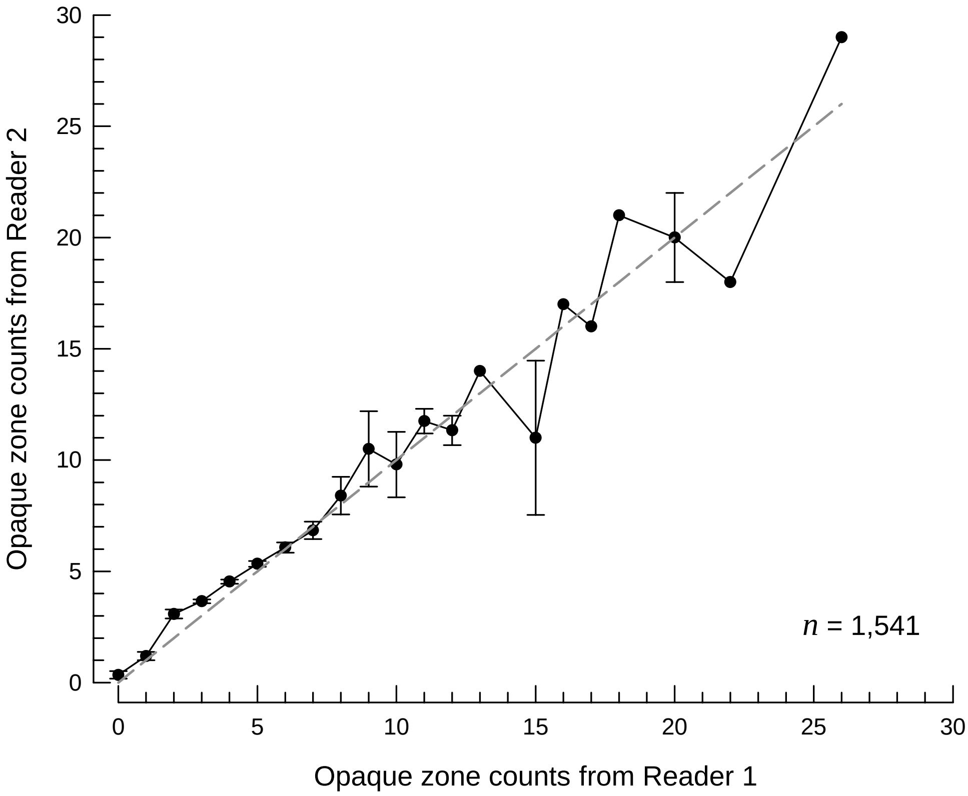

Figure 7.2. Age bias graph for pairwise comparison of opaque zone counts in *Pagrus auratus* otoliths (n = 1,541) between the two primary readers (JN and GJ). Error bars represent ± 2 SE and the dashed line the 1:1 equivalence.

7.3.3 Marginal increments analysis

The distributions of the marginal increment values for the otoliths of this species were bimodal in September to December in the Metropolitan region (Fig. 7.3). The marginal increments on otoliths with ≥ two opaque zones increased on average from less than 0.2 in September to greater than 0.7 in December of the following year (Fig. 7.3). Otoliths with an opaque zone visible on their outer margin were not recorded in the Metropolitan region until August (Fig. 7.3). By December, the prevalence of otoliths with an opaque zone on their outer edge, amongst the group of otoliths with a large marginal increment, had become very high, but fish with such otoliths were not found after this month.

It is thus evident that, in the Metropolitan region and irrespective of the number of opaque zones, the marginal increment values increased progressively from their minima at some time between August and December to their maxima in the same months of the following year. The fact that the distributions were typically bimodal during those months, due to the fact that a translucent zone had only become visible on the outer edge of the otoliths of some individuals at that time and thus led to the delineation of the outermost opaque zone, demonstrates that a single opaque zone is formed in the otoliths of *P. auratus* each year. Thus, the number of opaque zones in the otoliths of *P. auratus* can be used for ageing the individuals of this species.

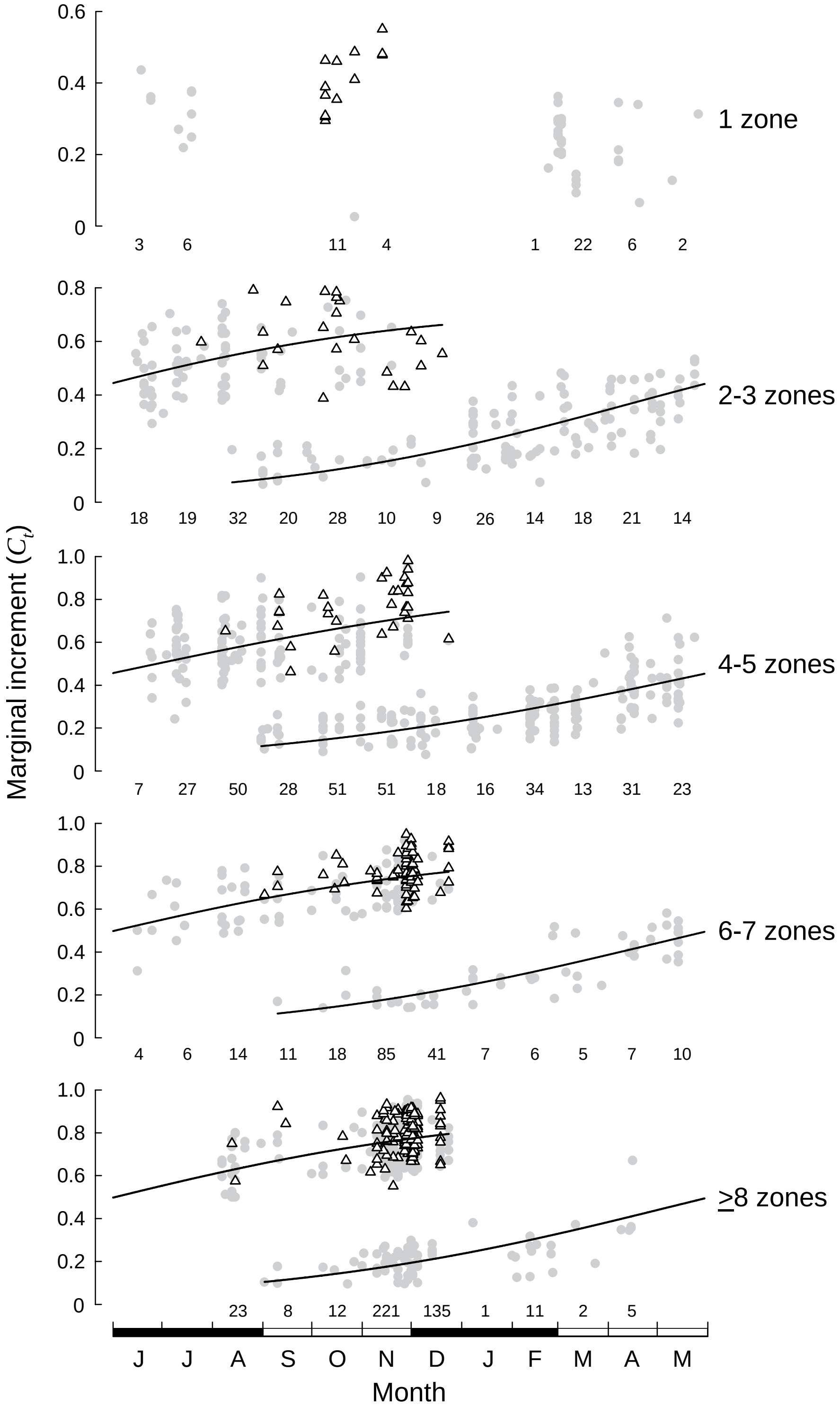

Figure 7.3. Marginal increments (C_t) on sagittal otoliths of *Pagrus auratus* from the Metropolitan region with translucent (grey circles) and opaque (white triangles) outer margins in each month. Otoliths have been separated into groups by the number of completed opaque zones as follows, (a) One zone, (b) two and three zones, (c) four and five zones, (d) six and seven zones and (e) ≥ eight zones. Sample size for each month is shown. A logistic regression function has been fitted to the C_i values (black line). On the x-axis, closed rectangles represent winter and summer months and open rectangles the spring and autumn months (from Wakefield 2006).

7.3.4 Length and age composition

The majority of fish were obtained by commercial and recreational fishers (Table 7.2), and as a result *P. auratus* less than the minimum legal length (MLL) of 410 mm TL were poorly represented in samples. In addition, juveniles of this species, *i.e.* < *ca* 180 mm TL, were specifically targeted in each region. Such juvenile fish were only sampled in the Metropolitan and South regions (Fig. 7.4), however their occurrence in the North region cannot be ruled out. Notwithstanding this, *P. auratus* ranged in size from 183 to 948 mm TL in the North region, 90 to 1056 mm TL in the Metropolitan region and 100 to 969 mm TL in the South region.

The length compositions between females and males were very similar within the North, Metropolitan and South regions, but differed markedly between regions (Fig. 7.4). One broad mode was present in the length compositions of females and males in the North region, with fish ≥ MLL displayed a general decline in numbers from *ca* 470 to 840 mm TL (Fig. 7.4). In contrast, the length compositions of females and males of *P. auratus* ≥ MLL in the Metropolitan region were bimodal. Fish between the MLL of 410 and 500 mm TL made the greatest contribution to the first mode, while those from 780 to 920 mm TL contributed most to the second mode. The fish that contributed to the second/larger mode almost entirely consisted of individuals caught from the annually occurring spawning aggregation in Cockburn Sound (Fig. 7.4). In the south region, the length compositions of females and males were similar to that in the North region, displaying one broad mode. The numbers of fish ≥ MLL in this region displayed a precipitous decline from *ca* 600 to 900 mm TL, however this mode was not as defined as sample sizes were much lower (Fig. 7.4).

Pagrus auratus ranged in age from 1.8 to 26.2 years in the North region, 0.3 to 28.8 years in the Metropolitan region and 0.8 to 32.6 years in the South (Table 7.4). The combined sample sizes of fish aged in the North region are larger than that of the length compositions as a sex was not determined for some fish.

The age compositions of *P. auratus* in the North, Metropolitan (excluding Cockburn Sound) and South regions were all essentially bimodal with fish of 3 to 5 years being well represented in most years. In almost all years and in each region the numbers of fish declined precipitously from *ca* 3 to 5 years to 10 years, with an absence of older fish, *i.e.* > ten years. Such older fish were only caught from the annually occurring spawning aggregation in Cockburn Sound, where fish were predominantly between 7 to 14 years of age (Fig. 7.5). Given the lack of older fish caught in the entire WCB with the exception of Cockburn Sound, it was difficult to determine annual recruitment variability, as trends in the abundances of age cohorts could not be followed between years. Variations in the abundances of age cohorts could be observed in the age compositions of *P. auratus* in Cockburn Sound from 2002 to 2004. There were three year classes in the age compositions from Cockburn Sound that consistently displayed higher abundances between years (Fig. 7.5). They included the 1991 year class (*i.e.* 11 year old fish in 2002, 12 year olds in 2003 and 13 year olds in 2004), 1992 year class (*i.e.* 10 year olds in 2002, 11 year olds in 2003 and 12 year olds in 2004), and the 1996 year class (*i.e.* 7 year olds in 2003, and 8 year olds in 2004, Fig. 7.5). Based on this, years of strong recruitment can be between 1 to 5+ years apart.

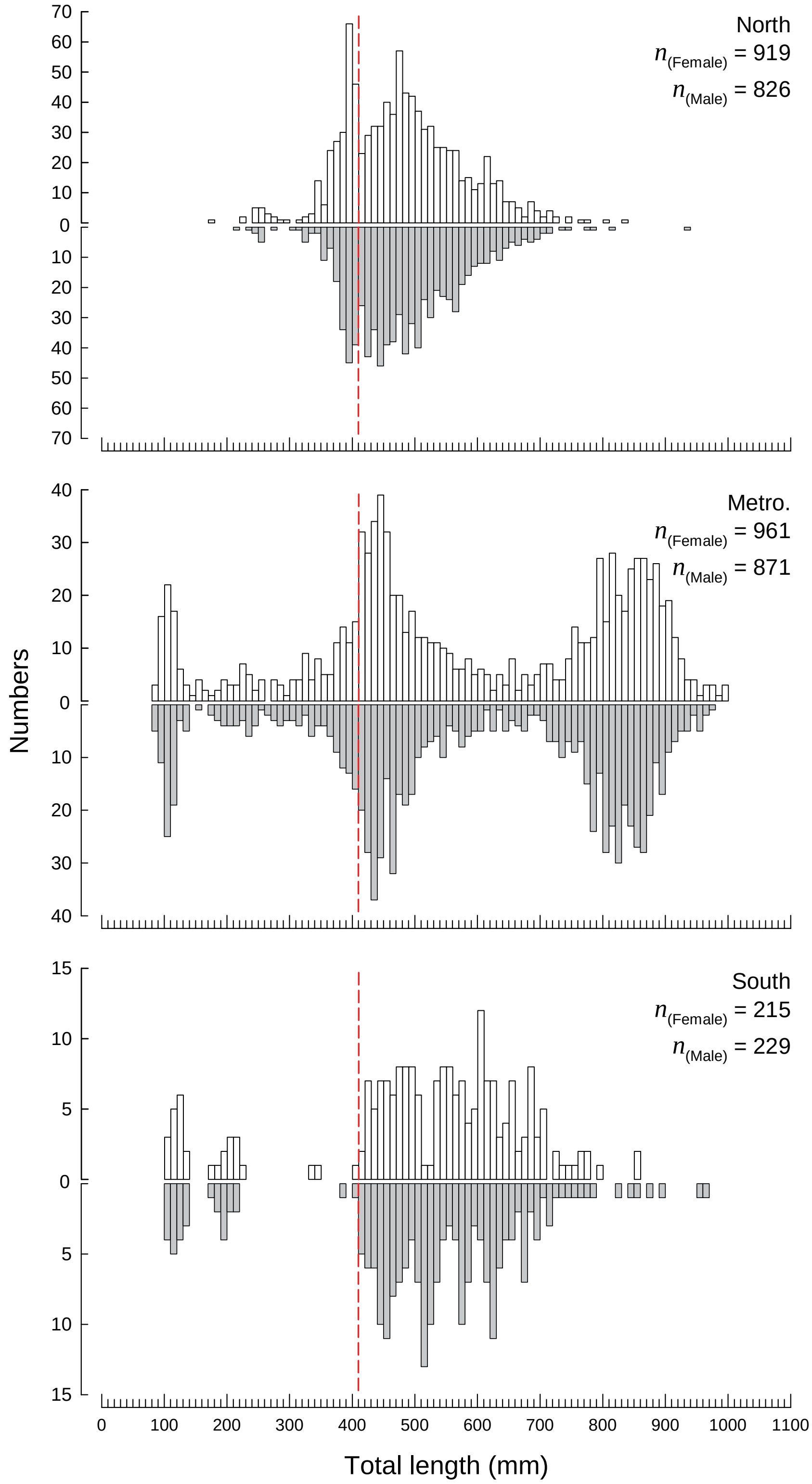

Figure 7.4. Length frequency distributions for female (white bars, above x-axis) and male (grey bars, below x-axis) *Pagrus auratus* from the North, Metropolitan and South regions (Wakefield 2006). Juveniles with indeterminate gonads were equally assigned to data sets for males and females. The red line represents the MLL of 410 mm TL.

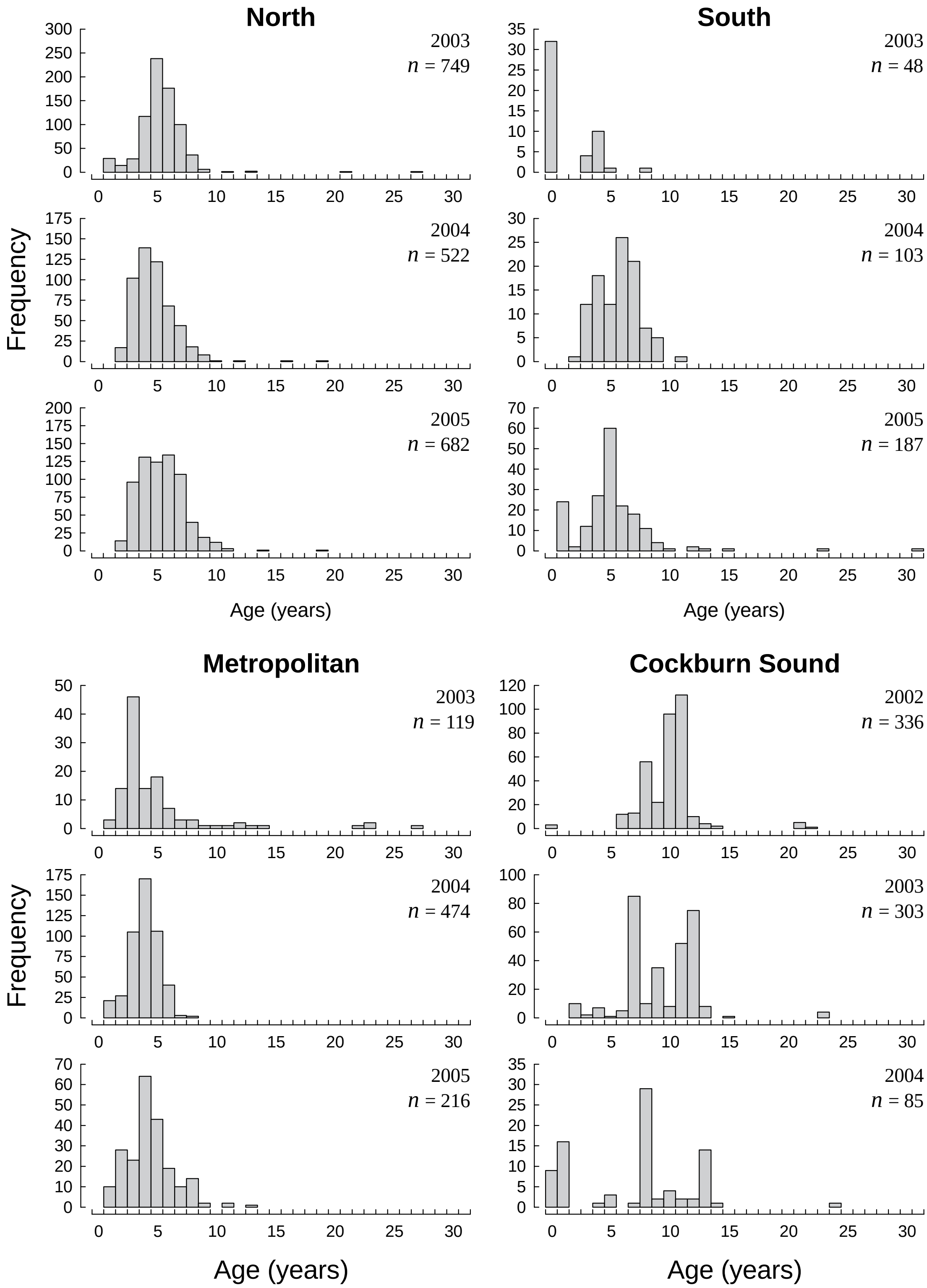

Figure 7.5. Age frequency distribution of *Pagrus auratus* in the North, South and Metropolitan regions in 2003 to 2005, and in Cockburn Sound in 2002 to 2004 (Wakefield 2006).

7.3.5 Growth

The von Bertalanffy growth curves provided acceptable fits to the total lengths at age for both sexes in the three regions as was demonstrated by the coefficients of determination that ranged between 0.56 and 0.89 (Table 7.5). The von Bertalanffy growth curves for females and males differed between each other and among those of the same sex in each of the three regions (likelihood ratio test, $p < 0.05$). However, the estimated lengths, from the von Bertalanffy equation, of females at 12 years of age, *i.e.* 663, 887 and 766 mm TL, and of males of the same age, *i.e.* 694, 877, 755, from the North, Metropolitan and South regions, respectively, differed by 4.5%, 1.1% and 1.4 % only. Thus, as is often the case with such statistical test that are based on large sample sizes, the differences, while statistically significant were shown to be not significant biologically between the sexes in each region.

Conversely, the differences in the estimated lengths of females between the three regions were much larger. For example, the North and Metropolitan regions differed by 25.3% and by 13.4% and 13.6%, respectively, from the South region. Likewise the differences in the estimated lengths of males between the three regions were much larger. For example, the North and Metropolitan regions differed by 20.9% and by 13.9% and 8.1%, respectively, from the South region. This suggests *P. auratus* in the Metropolitan region are capable of attaining a much larger size than those in the North and South regions. This point is illustrated by the fact that, in all cases, the von Bertalanffy growth equations for females, males and sexes combined, the asymptotic length (L_∞) was far greater for *P. auratus* from the Metropolitan region. Considering the insignificant biological differences between the growth of females and males in each region, but significant differences for both sexes between regions, the length at age data for females and males have been combined and used for assessments of this species in each region separately.

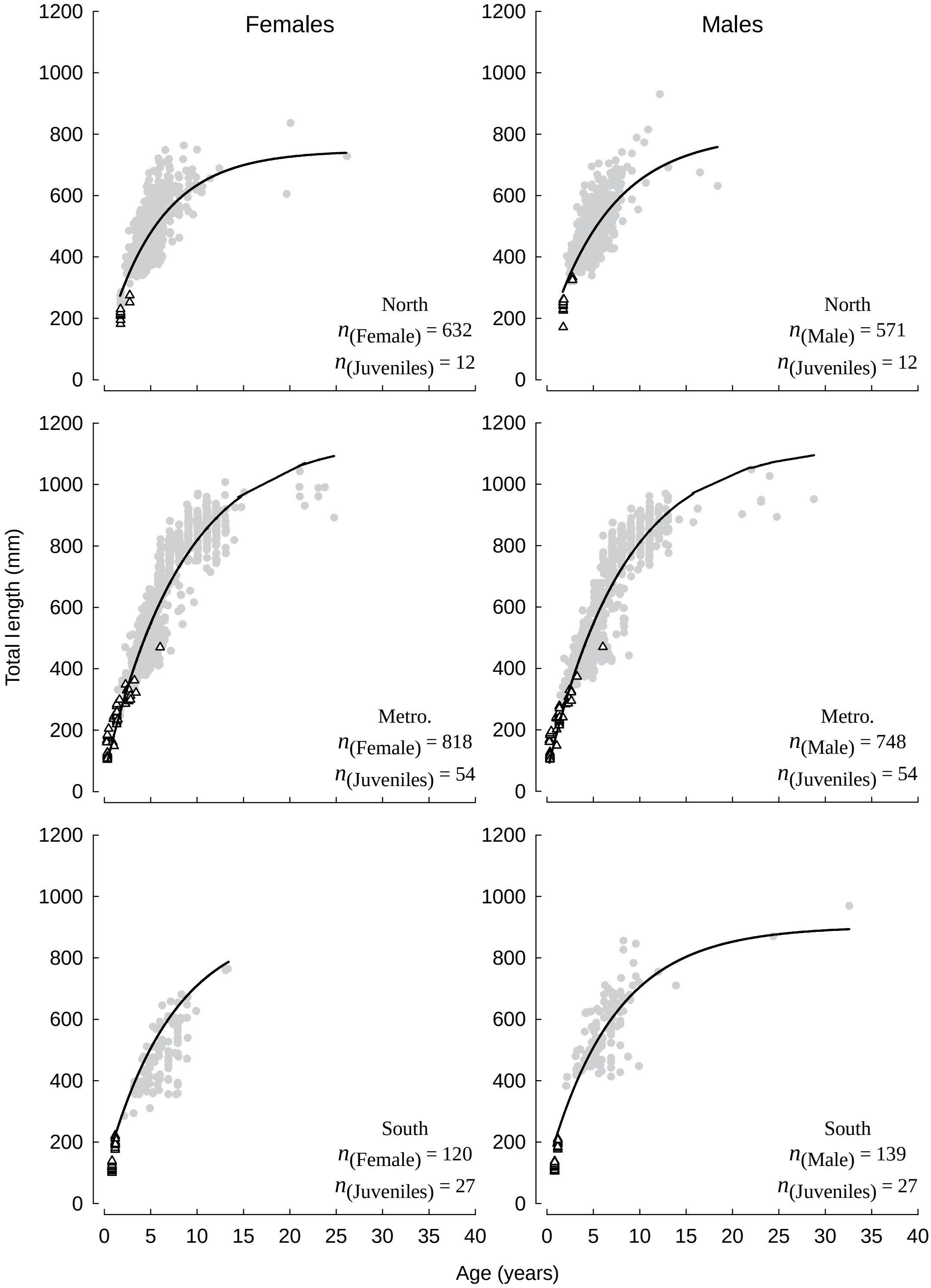

Figure 7.6. von Bertalanffy growth curves (red line) fitted to lengths at age of female (grey circles), male (grey circles) and juvenile (white triangles) *Pagrus auratus* from the North, Metropolitan and South regions (Wakefield 2006).

Table 7.4. von Bertalanffy growth parameters (± 95% C.I.) for female and male *Pagrus auratus* from the three regions.

	L_∞ (mm, TL)	k (yr^{-1})	t_o (yr)	A_{max}	TL_{max}	n	r^2
North							
Female							
Estimate	746	0.17	-0.93	26.2	832	644	0.60
Upper	809	0.21	-0.39				
Lower	648	0.13	-1.47				
Male							
Estimate	803	0.15	-1.30	18.4	947	583	0.60
Upper	900	0.19	-0.60				
Lower	706	0.10	-2.00				
Metro							
Female							
Estimate	1150	0.12	-0.41	24.8	1051	872	0.89
Upper	1199	0.13	-0.22				
Lower	1101	0.11	-0.60				
Male							
Estimate	1127	0.12	-0.46	28.8	1056	793	0.88
Upper	1178	0.13	-0.24				
Lower	1075	0.11	-0.67				
South							
Female							
Estimate	918	0.14	-0.84	13.3	879	147	0.80
Upper	1119	0.20	-0.15				
Lower	717	0.07	-1.53				
Male							
Estimate	902	0.14	-0.98	32.6	993	166	0.78
Upper	1006	0.18	-0.41				
Lower	798	0.10	-1.55				
Sexes combined							
North							
Estimate	786	0.15	-1.37			1227	0.56
Upper	846	0.18	-0.85				
Lower	725	0.12	-1.89				
Metro.							
Estimate	1136	0.12	-0.42			1689	0.88
Upper	1171	0.13	-0.27				
Lower	1101	0.11	-0.56				
South							
Estimate	925	0.13	-1.16			313	0.71
Upper	1028	0.16	-0.56				
Lower	822	0.10	-1.75				

L_∞, hypothetical asymptotic length at an infinite age, TL, total length, k, growth coefficient, t_o, hypothetical age at zero length, A_{max}, maximum age, TL_{max}, maximum total length, n, sample size, r^2, coefficient of determination.

7.4 Discussion

This study has successfully provided baseline information on the age and growth of *P. auratus* for the main fishing locations in the West Coast Bioregion (WCB) from 2002 to 2005. Where possible, large sample sizes were collected in an effort to achieve adequate representation of the older age classes in each region. Apart from Cockburn Sound, the age compositions in most years were essentially unimodal with the highest numbers of fish represented by the 3, 4, or 5 year old fish. Very few fish older than 10 years were caught in the entire WCB, with the exception of Cockburn Sound. These data therefore indicate that the fishery is dependent on a few younger year classes despite fish older than 25 years being caught in each region. *Pagrus auratus* are known to live to 30+ years in Australian waters (McGlennon *et al.* 2000; Wakefield 2006; Jackson 2007) and to 55-60 years in New Zealand (Francis *et al.* 1992).

The lack of older fish in the entire age compositions from the North, Metropolitan and South regions, with the exception of Cockburn Sound made it difficult to determine annual recruitment variability, as trends in the abundances of age cohorts could not be followed between years. Variations in the abundances of age cohorts were observed in the age compositions of *P. auratus* in Cockburn Sound from 2002 to 2004, with the 1991, 1992 and 1996 year classes contributing higher abundances of fish. Thus, based on this limited evidence it appears that years of strong recruitment can be between 1 to 5+ years apart. Previously, recruitment of *P. auratus* in the WCB has been assumed to be highly variable due to highly variable catches and catch rates (StJohn & King 2006). Trawl surveys conducted within Cockburn Sound since 1999 that specifically target 0+ *P. auratus*, have shown only two strong years of recruitment, *i.e.* the 1999 and 2007 years classes (Johnston *et al.* 2008). Thus, from this information it appears that years of strong recruitment could in fact be up to 8 years apart. Studies of recruitment variability of *P. auratus* elsewhere in New Zealand and Australia have also shown strong interannual variation (Francis 1993; Fowler & Jennings 2003; Hamer & Jenkins 2004).

The growth of *P. auratus* differed significantly between all three regions but was not biologically significant between females and males in each region, *i.e.* the estimated lengths from the von Bertalanffy growth equations for fish at 12 years of age did not differ by more than 5%. Given the limited biological significance between growth curves of females and males in each region and as a common growth curve is traditionally used for assessing the status of the stocks of *P. auratus*, the von Bertalanffy growth parameters using the length at age data of both sexes was derived and used to assess the stocks in each region (see Wise *et al.* 2007).

The important issue for management is the significance of the locations of the annually occurring spawning aggregations of *P. auratus* in Cockburn and Warnbro Sounds and to a lesser extent Owen Anchorage, which currently are the only such locations in the WCB. It may be possible that other large spawning aggregations occur elsewhere within the WCB, although it seems unlikely given the long history of intensive fishing in the bioregion and the relative paucity of protected embayments along this stretch of coast. The contribution of recruitment from such unidentified spawning/nursery locations that may occur within the WCB is not known. As noted in Section 6.4, future research should investigate the relative importance of the contribution of *P. auratus* recruits from the nearshore marine embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound to the adult populations within the WCB.

8.0 Assessment of management options

D. Gaughan, J. StJohn and I. Keay

Objective 4 **Develop a suite of alternative management scenarios to assist the multiple fishing sectors of the bioregion to select and adopt an optimal management strategy**

8.1 Introduction

The demersal scalefish "fishery" in the West Coast Bioregion is for many reasons one of the more complex groups of fishing operations to manage in the state. These complexities include the large variety of species caught (> 100 species, but with few target species), the biological differences between the target species, including differing susceptibility to post-release mortality, and the varying importance of different fish species to each fishing sector. Most important is the proximity of the fishery to Perth, the major population centre in Western Australia. Consequently, the considerable recreational participation gives this fishery a substantial social value as well as the commercial value. While research on the biology and stock assessment of fish typically underpins the management process, research activities can initially be disjunct from the management process, which must also consider stakeholder and political expectations as well as the actual logistics and costs of alternative management systems. Stakeholder expectations are critical to the management outcomes and thus need to be managed accordingly.

The elements of knowledge sharing and provision of advice leading up to the objective of developing an optimal management strategy, including important consultative processes and tracking of both fisher and policy perceptions, are reported here. Examples of how the knowledge from this project was utilized within the process of developing management options are provided, followed by a more succinct account of how Objective 4 was achieved.

8.2 Activities and outcomes

The activities undertaken to address Objective 4 were as follows, and are divided into the period before and after finalisation of the stock assessments for the key demersal species.

Prior to completion of the stock assessments

- Compilation of biological and fishery data for the purpose of extension to stakeholders (*e.g.* non-specialist presentations)
- Stakeholder meetings (direct education and canvassing views)
- Tracking views of internal and external stakeholders relative to potential management options (indirect via media and internet)
- Consideration of a conceptual model to assess alternative management options

Post completion of stock assessments

- Provision of advice on the requirements for reductions in fishing mortality
- Consultation with stakeholders
- Provision of scientific advice
- Development of potential management options

- Reporting on policy directions and stakeholder feedback

The major elements that contributed to these activities and outcomes are described below.

8.2.1 Stakeholder meetings

The desktop study of community consultation approaches was completed in December 2003 (Appendix 1). Given the complex and sensitive nature of developing management options for this group of west coast “fisheries”, the stakeholder meetings focussed on the contemporary research activities (Appendix 2), *i.e.* the biology and ecology of dhufish and pink snapper, plus the results of the project on increasing the survival of released fish, *i.e.* experiments to assess rates of post-release mortality. The presentations of these results were preceded by talks aimed at promoting an understanding of the essential elements of fish population dynamics (including spatial aspects) relevant to fisheries management. This general background was provided so that the future management of dhufish and pink snapper in WA could be placed in the context of previous experience with fisheries management in Australia and internationally.

8.2.2 Stakeholder views and perceptions

This section highlights the iconic status of dhufish to Western Australians. There is no other single species in WA that has generated as much interest by recreational fishers and conservationists alike. Dhufish are the only targeted fish species in WA that has:

- been the topic of a workshop on its sustainability, attended by a diverse range of stakeholders,
- its own welfare group (Dhufish Action Group, DAG) comprising recreational fishers who are concerned about its sustainability.

Pink snapper have not attained quite the same iconic status as dhufish in WA, but are also a favourite species throughout most of southern Australia, as their range extends along all of the temperate Australian coast and into sub-tropical regions (*i.e.* from north of Moreton Bay in southern QLD to Northwest Cape in WA).

Due to the high level of public interest in dhufish and pink snapper, issues about these two species in WA are publicly sensitive and highly emotive among recreational fishers. This high level of interest in the sustainability of pink snapper and dhufish in WA is evidenced in the following sections (Media and Internet, Dhufish Workshop, Dhufish Action Group). Also, we searched for Departmental records relevant to dhufish to indicate the high level of interest in managing this species.

Media and internet

The following examples are not exhaustive but are provided here to highlight the types of sentiments and concerns expressed by stakeholders.

The popular magazine *Western Angler* has produced several editorials about dhufish sustainability and management over recent years. For example, an editorial in 2005 discussed the management arrangements for the recreational and commercial sectors at that time, and explored potential management options for recreational fishers and the need for sustainability. In 2006 there was a further editorial, entitled ‘*Time for decisions on dhuies*’, that pursued the need to develop management options for dhufish.

The *Western Angler* has a website-based forum where anglers can discuss fishing issues of interest (http://www.westernangler.com.au/forum/). Anglers must register with a distinct user name to participate (initiate a topic or reply to an issue raised). The forum is divided into discussion groups and each site is assigned a moderator to manage the discussion. One of the discussion groups is entitled 'Fisheries Management and Environmental Issues'. Samples of topics since August 2005 include 5 topics about dhufish and pink snapper in the Perth metropolitan region (Table 8.1). These five topics had a total of 450 replies and nearly 20,000 hits. It is important to note that these numbers represent only the initial interest in these subjects as the discussion may branch out from individual replies generating a new discussion with further replies and many more hits.

Table 8.1. The numbers of written replies to an initial topic raised by a user, categorized by area and species, over a given time period. Hits on topic are the number of times the topic was visited.

Area	Fish Species	Subject Initial Topic	Topic related		
			Replies	Hits	Period
Metro	Dhufish	Rottnest Island no fishing zones	181	5851	20-27/7, 2006
Metro	Dhufish & pink snapper	Management	122	4576	2/8–21/10, 2005
		Management	28	1408	3/2-2/3, 2006
Cockburn Sound	Pink snapper	Man-made island shipping terminal	30	1443	27/7-18/8, 2006
		Fishing	89	6585	18/8-31/8, 2006

Dhufish Workshop

The West Australian Dhufish workshop (Pagano & Fuller 2006) held on June 12, 2004 was funded by Fishcare WA and jointly hosted by Recfishwest and DOFWA. The sentiments and concern regarding dhufish were summed up in one of the keynote speeches at the dhufish workshop, '*…sustainability of dhufish is an integral part of being Western Australian, because dhufish are an iconic species. If we have to face the rest of the world and say that the one fish that we have that is unique and highly valued we would feel shame if it were not looked after and we couldn't tell everybody about the fishing experience*'.

The workshop was divided into three sessions (Table 8.2). In the first session entitled 'Current Knowledge', the information from research on the biology and physiology of dhufish was presented. Session 2 entitled 'The Issues' comprised speakers from each sector. Session 3 entitled 'Current and future management' discussed historical, current and future management of all sectors, as well as the prognosis for dhufish sustainability. Each session was followed by an open discussion where questions from the floor were answered by the panel of speakers.

Over 100 people attended the workshop and had the opportunity to partake in discussions throughout the day. The executive summary of the workshop proceedings ends with '*A clear outcome from the workshop was the unanimous concern among all presenters that dhufish management must change and change soon if we are to protect this iconic species for future generations.*' A key benefit for managers, policy-makers and stakeholders was the increased understanding of one another's concerns, which flowed from the frank and open discussions during the workshop.

Table 8.2. Table of contents of the Proceedings of the Western Australian Dhufish Workshop 2007

(Pagano & Fuller 2006).

	Chapter title	Author	Institution
	Section 1		
1.1	Biology of the West Australian dhufish *Glaucosoma hebraicum*	A Hesp, I Potter and N Hall	Centre for Fish and Fisheries Research, Murdoch University
1.2	Dhufish Aquaculture	G Jenkins	Aquaculture Development Unit, Challenger TAFE
1.3	Stock Assessment of Dhufish *Glaucosoma hebraicum*	R Lenanton and J StJohn	Finfish Research, DOFWA
1.4	Dhufish *Glaucosoma hebraicum* research by the Department of Fisheries	D Gaughan and J StJohn	Finfish Research, DOFWA
	Section 2		
2.1	Commercial Fisher Perspective	W Aitchison	Commercial Wetline Operator
2.2	Recreational Fisher Perspective	P Shinnick	Member of Lancelin Angling and Aquatic Club
2.3	Charter Operator Perspective	A Bevan	Charter boat Owner/Operator
	Section 3		
3.1	Managing the Recreational Catch	A Cribb	Recreational Fisheries Program, DOFWA
3.2	Managing the Commercial Catch	I Curnow	Wetline Program, DOFWA
3.3	Sustainability and Effective Management – Available Tools	G Leyland	WA Fishing Industry Council
3.4	Future Management Scenarios for dhufish	F Prokop	Recfishwest
3.5	Integrated Fisheries Management – Challenges	P Rogers	CEO, DOFWA

DAG – Dhufish Action Group

Arising from concern over dhufish sustainability, a small group of recreational fishers initiated DAG in 2004. Indeed, members of DAG were convinced that metropolitan fish stocks, particularly dhufish and pink snapper, were depleted. Through liaising with DoF staff DAG has endeavoured to gain a clear understanding of the interim results from this current project to help them formulate their views. Although this group consisted of a relatively small number of anglers, they made a conscientious effort to understand the population dynamics of dhufish (albeit preliminary at that time) and then to cast these against their own experiences. DAG subsequently submitted petitions to the Fisheries Minister (Appendix 3) as well as producing a management document calling for specific management of the metropolitan area (Appendix 4).

8.2.3 Internal stakeholders: contribution to management and policy development

DOFWA has recognized the iconic status of dhufish and has also been cognisant of both the increased commercial catches of the West Coast Demersal Scalefish Fishery (WCDSF) and the perceived increases in catch by the recreational sector. As the “demersal scalefish fisheries” of the West Coast Bioregion were the first “finfish fisheries” to be subjected to the IFM process, they have been the subject of considerable research, policy development and communication within and external to DOFWA.

Between 1988 and 2006, there have been 96 Departmental files created on the subject of WCB wetline and recreational sustainability including IFM, with numbers increasing steadily over the past few years (Fig. 8.1). The increasing number of files can be attributed to increasing stakeholder involvement in developing management options and the complexity of bringing the commercial-wetline and recreational fisheries that target demersal scalefish in the WCB into a single management framework.

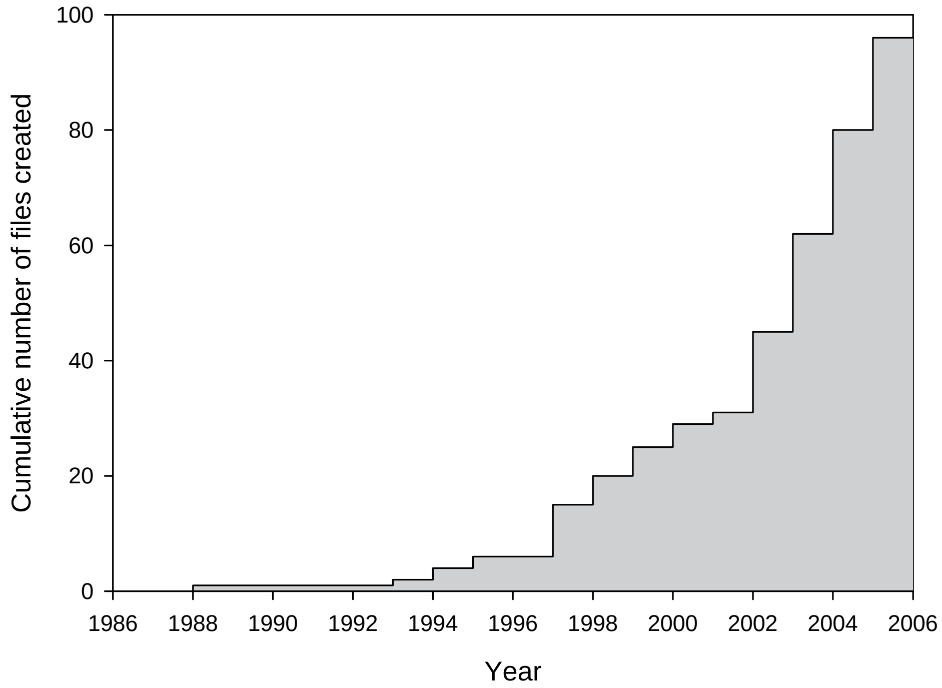

Figure 8.1. Cumulative number of files on issues pertaining to the scalefish fisheries of the WCB (*i.e.* Wetline and IFM issues) created in each year by DOFWA.

Since 1999 DOFWA published 18 papers (see list below) on issues concerning management of the commercial (wetline) and the recreational fishery in the WCB (see below). This series of documents have been required to ensure that the finer details of a complex array of inter-related issues are available for both internal and external stakeholders. These documents continue to provide a record of progress that ensures ongoing development is underpinned by a transparent history.

The Fishery Management Papers and Fishery Research Reports published since the completion of this project can be found on the DOFWA website (http://www.fish.wa.gov.au/sec/about/pubs/index.php?0706).

List of Fishery Management Papers

Crowe, F., Lehre, W. and R. J. C Lenanton (1999). A study into Western Australia's open access and wetline fisheries. Fisheries Research Report No. 118, 142 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/frr/frr118/frr118.pdf.

FMP 134. (2000) Management Directions for Western Australia's Coastal Commercial Finfish Fisheries Perth, W.A. : Fisheries Management Paper No. 134, 56p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp134/fmp134.pdf

FMP 135. (2000) Protecting and Sharing Western Australia's Coastal Fish Resources Perth, W.A. : Fisheries Management Paper No. 135, 96p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp135/fmp135.pdf

FMP 136. (2000) Management directions for Western Australia's recreational fisheries. Fisheries Management Paper No. 136, 64 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp136/index.php.

FMP 139. (2000) A quality future for recreational fishing on the west coast. U1 - Fisheries Management Paper No. 139, 105 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp139/index.php.

FMP 153. Harrison, N. (2001) A five year management strategy for recreational fishing on the west coast of Western Australia, Fisheries Management Paper No. 153, 114 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp153/index.php.

Fletcher, W. J., and I. Curnow (2002) Processes for the allocation, reallocation and governance of resource access in connection with a framework for the future management of fisheries in Western Australia. A scoping paper developed for consideration and use by the Integrated Fisheries Management Review Committee, Fisheries Management Report No. 7, 58 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/comm/broc/mr/mr007/fmr007.pdf.

FMP 187. Harrison, N. (2004) Proposals for community discussion on the future management of pink snapper fishing in Cockburn Sound and surrounding waters. Fisheries Management Paper No. 187, 32p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp187/index.php.

FMP 190. (2005) Proposed management arrangements for the West Coast commercial 'wetline' fishery: a discussion paper, Fisheries Management Paper No. 190, 80 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp190/index.php.

FMP 191. (2005) Access and allocation arrangements for the commercial 'wetline' fisheries: proposals for discussion: a report to the Minister for Fisheries prepared by the Commercial Access Panel. Fisheries Management Paper No. 191, 71 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp191/index.php.

FMP 206. (2006) Recommended management arrangements for the west coast commercial 'wetline' fishery: a report to the Minister for Fisheries prepared by the West Coast and Gascoyne Management Planning Panel. Fisheries Management Paper No. 206, 61 p., Department of Fisheries, Western Australia, http://www.fish.wa.gov.au/docs/mp/mp206/fmp206.pdf.

FMP 207. (2006) Recommended access and allocation criteria for the west coast and Gascoyne commercial 'wetline' fisheries: a report to the Ministry of Fisheries prepared by the Commercial Access Panel. Fisheries Management Paper No. 207, 64 p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp207/fmp207.pdf.

FMP 220. (2007) Management of the Houtman Abrolhos system: a draft review 2007-2017: prepared on behalf of the Minister for Fisheries by the Department of Fisheries (Western Australia) on advice from the Abrolhos Islands Management Advisory Committee Perth, W.A. Fisheries Management Paper No. 220, 88 p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp220/fmp220.pdf.

FMP 221. (2006) Outcomes of the wetline review: the Minister for Fisheries' proposed decisions for the future management of the West Coast and Gascoyne commercial 'wetline' fisheries Perth, W.A. Fisheries Management Paper No. 221, 39 p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp221/fmp221.pdf

FMP 224. (2007) Outcomes of the wetline review: the Minister for Fisheries' decisions in relation to the future management of the West Coast and Gascoyne commercial 'wetline' fisheries Perth, W.A.: Fisheries Management Paper No. 224, 27 p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp224/fmp224.pdf.

FMP 225. (2007) Managing the Recreational Catch of Demersal Scalefish on the West Coast: Future Management Scenarios for Community Consideration Perth W.A. : Fisheries Management Paper No. 225, 48p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp225/fmp225.pdf

FMP 228 (2008) A Strategy for Managing the Recreational catch of Demersal Scalefish in the West Coast Bioregion Perth, W.A. : Fisheries Management Paper No. 228, 26 p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp228/fmp228.pdf

FMP 231 (2008) A Strategy for Managing the Recreational Catch of Demersal Scalefish in the West Coast Bioregion: Decisions by the Minister for Fisheries Perth, W.A.: Fisheries Management Paper No. 231, 17p., Department of Fisheries, Western Australia. http://www.fish.wa.gov.au/docs/mp/mp231/fmp231.pdf

8.2.4 Conceptual model to assess alternative management options

Associate Professor Norm Hall (Centre for Fish and Fisheries Research, Murdoch University) developed the specifications for a conceptual model to use as a basis for considering the impacts of alternative management arrangements on different sectors and geographic regions of the fishery. Although the implementation of the model did not occur (see explanation in Section 8.3.1) the specifications are provided in Appendix 5.

8.3 Summary of the development of an optimal management strategy

This account of the how the management process for the WCDSF progressed in response to the knowledge gained in this project contributed to the development and subsequent consideration of alternative management solutions has been divided into the periods before and after the release of Part 1 of this report (Wise *et al.* 2007). Part 1 of the report presented the results for the stock assessments, including catch and effort data from each of the recreational, commercial and charter sectors. The information gathered in the project, and consolidated with data from these other sources, contributed to (i) the implementation of new management actions and (ii) the development of potential management solutions that can be considered to constitute alternative management scenarios, which when combined produce an optimal management strategy. "Optimal" in this case will be the most pragmatic balance of various options that will meet the sustainability needs of the fish resources and the economic and social needs of stakeholders, within a cost effective management regime.

Since 2000, the Department of Fisheries has been undertaking several overarching management processes concurrently. Integrated Fisheries Management (IFM) is a government initiative to improve multi-sectorial management of fish stocks, including a focus on formal allocation of catch (access) to the different fishing sectors within an overall goal of sustainability of the resource. IFAAC (Integrated Fisheries Allocation Advisory Committee) is an independent committee instigated to consult widely with clients, stakeholders and community groups' and provide expert recommendations to the Minister in relation to allocation of catch shares between sectors.

The Wetline Review has been a process focussed on establishing a formally managed commercial fishery (or fisheries) for those operators that utilize the state's scalefish resources beyond any existing management plans. Two panels were formed to provide advice for implementing scalefish-fisheries management. A Management Planning Panel (MPP) was appointed to develop options for the specific management arrangements for the fishery and a Commercial Access Panel (CAP) was appointed to devise a fair and equitable method of determining who will have access to the fishery and their level of allocation.

The Wetline Review and IFM processes have dealt with the inherent complexities of assimilating the range of stakeholder expectations, both within and between sectors. Progression through these processes has necessitated the frequent input of information obtained in this project to ensure that higher-level management directions (*e.g.* expectations from IFAAC) were cognisant of the contemporary knowledge of the biology and status (interim assessments) of the key species in the fishery. This project has therefore played a crucial role in developing potential management systems for both the sustainability and allocation of the demersal scalefish resource in the WCB.

8.3.1 Prior to completion of the stock assessments (up to 2007)

Initial planning and management decisions

The initial focus for the overarching management of the WCDSF resource was the commercial sector. The first step achieved in developing optimal management solutions for the WCDSF was to recognize that the WCB in its entirety was not necessarily the appropriate spatial scale for management, and that some level of subdivision into zones within the bioregion would be required. The preliminary results from this study underpinned a significant shift in the management philosophy from 2000, at which time the concept of marine bioregions (in this case the West Coast Bioregion) was identified as the preferred spatial basis for managing the state's coastal (or "wetline") commercial fisheries and for cross-sectoral management and allocation of fisheries resources (FMP 134, FMP 135). These early results (*i.e.* 2003-2004) from this project confirmed that each of dhufish and snapper did not exist as populations that mixed widely through the WCB so the management of their exploitation may need to consider spatial solutions. Subsequently, the results of the biological studies further confirmed that zonation was required. Results presented to stakeholders at the first round of meetings showed that growth rates of dhufish varied along the WCB and that timing of peak reproductive activity also varied.

This study therefore provided the evidential basis for the fisheries management process to adopt a strategy of zonation of the WCB (FMP 190). This was achieved early on in the process and was critical for making the decision that commercial fishery zones were required to meet biological characteristics of the key demersal species.

Consideration of alternative scenarios to develop optimal management solutions

In conjunction with the latitudinal variations in biology of the species, there were also variations in levels of fishing effort applied by the different sectors and in the composition of the demersal scalefish catches. This information, part of the additional analyses consolidated within this project, provided the basis for the zonal boundaries within the WCB for the commercial sector of the WCDSF. Thus, the biology and spatial dynamics of the stocks dictated that some level of zonation should be considered, while the catch history confirmed the need and dictated the location of the boundaries.

An important additional consideration to the regional differences in catch and effort dynamics amongst the sectors was the regional variability in success at obtaining samples representative of the age composition of the species. In turn, this indicated that there would be difficulties in applying the obtained age composition data to a single stock assessment model, for each species, that would encompass the spatial extent of a stock within the entire WCB.

Finally, this project attempted to use catch rate data as an index of abundance for each species, but concluded that this was not possible at a level that would allow the catch rate data to be used in a formal fisheries stock assessment model. When considered alongside the zonal variability in sources of the age composition data, it became apparent that formal stock assessment models of the type that could provide biomass trajectories could not be developed for stocks across the whole bioregion, nor for zones within bioregions. As a consequence of these issues the proposed model structure developed to test alternative management scenarios (Appendix 5) could not be implemented as it relied on a stock assessment model that could model biomass of the stocks and, critically, predict biomass trajectories under different spatial and temporal combinations of fishing effort. At this time it was apparent that the stock assessment advice, and hence the means to assess alternative management scenarios would require a different approach.

The weight-of-evidence approach was thus adopted as the best means of determining stock status and risk levels, from which advice on adequacy of current levels of fishing effort could be provided. In addition, the weight-of-evidence approach could only be implemented at zonal scales so as to match with the fishery (both sectors) characteristics and hence the availability of representative samples of age composition. However, given that the key quantitative aspect of the weight-of evidence approach was the determination of fishing mortality from the age composition data, which relied on zonal-level sampling to provide representative results, the weight-of evidence approach was, by default, well aligned to the zonal approach to management. This approach and the advice that reductions in fishing mortality of 50-100% were required (depending on the zone and species), were supported as the most appropriate stock assessment method by an independent review undertaken in early 2007.

The unavoidable shift in assessment methods represented another facet of the project's progress towards providing advice on optimal management solutions. In this case, there was a shift in the expected form of the principal outcomes of direct relevance to assessing alternative management scenarios. Nonetheless, alternative scenarios were examined in detail, but in an additive sense rather than in a mathematically holistic manner. The development of documentation for management and the associated consultation that pertained to the shift in assessment methods and the resultant utilization of a weight-of-evidence approach occurred in parallel to the completion of Part 1 of this FRDC report; these processes are summarized in the following section (Section 8.3.2).

Implementation of a partial management solution

A partial management solution for the WCDSF implemented in 2007, was the closure of the Metropolitan Zone of the WCB to commercial fishing for demersal scalefish species. Information from this study contributed directly to the decision-making process that lead to the spatial closure. The advice from this project that the fishing mortality of dhufish in this zone needed to be significantly reduced expanded on a similar finding by Hesp *et al.* (2002)

that dhufish in the late 1990s were likely to be overexploited. Furthermore, the analysis of age composition data indicated that the number of old dhufish in the metropolitan region of the population had declined dramatically in the 10 years since Hesp *et al.* (2002) collected data on dhufish ages.

8.3.2 After completion of the stock assessments

Management measures

This section provides an overview of management and consultation that followed the stock assessment of the key demersal species provided in Part 1 of this report (Wise *et al.* 2007) and which has been summarized from FMP 231. Because the significant aspects of rationalizing the commercial sector of the WCDSF had occurred by this time, the management process was subsequently focussed on the recreational sector, including a recently begun review of the charter sector.

The stock assessment, ancillary biological and ecological information, along with information from other sources (*e.g.* catch and effort data for all sectors, patterns of recreational boat-based fishing gleaned from the 2005/06 survey data) provided the basis for consideration of a range of potential management options. The cyclical process shown below constituted the assessment of alternative scenarios, with the aim of developing optimal management solution from the range of scenarios and their component management measures.

(i) provision of scientific advice (*e.g.* completion of stock assessment),

(ii) development of potential management options

(iii) consultation with stakeholders

(iv) provision of scientific advice (*e.g.* assess impacts of potential management solutions on reducing fishing mortality)

(v) development of potential management options

(vi) etc

Thus, the package of management measures were developed to deliver the required reduction (50-100%) in catches described in Part 1 of this report. It is important to understand that each management measure contributes to the reduction in catches necessary to give these stocks a chance to rebuild and that no measure on its own will deliver the required reduction in catch. Furthermore, as the process for allocating sectoral shares is not yet complete, the status quo dictates that each sector needs to reduce their share of the catch by the required percentage. This remains the current management direction for achieving the recommended reductions in fishing mortality. In this case, the management aim is to reduce the commercial catch in the WCDSF to 50% of the 2005/06 level through implementation of a total allowable effort for the commercial fleet.

To ensure the ongoing recovery of stocks, an adaptive approach to management has been adopted. This approach will involve an ongoing review of the effectiveness of these management arrangements, and take into account the latest research information.

The recreational fisheries management package that has been currently implemented into the WCDSF was the result of an extensive public consultation process.

Management measures involving bag limits, possession limits, size limits and boat limits have been implemented. Overall they aimed at achieving a 5-10% reduction in demersal catch. In the Kalbarri, MidWest and South zones the potential reduction is higher compared to the Metro zone where these measures will most likely have negligible impact.

Other proposed management measures for the recreational sector included seasonal closures, gear restrictions and fishing competition restrictions but these have not been implemented. These and, in particular, seasonal closures aimed to achieve an additional 40% reduction in demersal catch by the recreational sector to add to the 5-10% reductions that would be achieved by the new bag limits, size limits, etc., noting that the commercial sector has already incurred new management restrictions expected to decrease catch by 50% of the 2005/06 level.

Further management measures may be implemented in the future. These await outcomes of a second independent review of the stock assessment advice, and a subsequent review of potential management options for the recreational sector.

Consultation

Community consultation on future management of the recreational sector's share of the catch of key demersal species on the west coast commenced in September 2007 with the release of Fisheries Management Paper 225 (FMP 225) "Managing the Recreational Catch of Demersal Scalefish on the West Coast; Future Management Scenarios for Community Consideration" for an eight week public comment period. FMP 225 exemplifies how the work undertaken in this FRDC project has contributed directly to developing options for fishery management through being supplied (and applied) in "real-time". FMP 225, published in 2007, is included as Appendix 6 in this report so as to provide a detailed account of the various management options that were considered to achieve the required reductions in fishing mortality. In addition, inclusion of FMP 225 provides a consolidated example of FRDC-funding having direct and timely application to fisheries management.

During the public comment period, the Department of Fisheries held public meetings at regional centres including; Geraldton, Hillarys, Fremantle, Mandurah, Bunbury, Busselton, Collie and Margaret River, to promote community awareness of the review process and the sustainability issues facing the fishery. Public comment was sought on a range of fisheries management tools that could be used to deliver the required reduction in catches of key indicator species in the West Coast Bioregion.

Valuable feedback and comments were received at these public meetings (approximately 620 people in total) and through 138 written submission received by the Department. Submissions clearly indicated that people agreed there is a sustainability problem with key demersal finfish on the West Coast and a new approach is required to manage the recreational catch.

On 28 March 2008, following consideration of feedback received on FMP 225, the Minister for Fisheries released Fisheries Management Paper 228 (FMP 228) "A Strategy for Managing the Recreational Catch of Demersal Scalefish in the West Coast Bioregion", which provided an overview of the public response to date and presented options for management.

A ministerial position paper - "Recommended changes to recreational fishing of vulnerable iconic fish in the West Coast Bioregion" – which recommended 11 changes to fisheries regulations and policy to achieve the required management outcomes and reduce the recreational catch of demersal species was released at the same time for public comment. The public comment period concluded on 7 May 2008.

Over 1350 submissions were received from individuals, representative groups and associations in response to the ministerial position paper. The Minister also met with representatives from key stakeholder groups to provide them with further opportunity for comment and discussion.

The key management measures that could contribute to an optimal management strategy include the following.

Bag limits

The proposal to reduce the mixed daily bag limit of Category 1 "high risk" fish from seven to four received a high level of support in public submissions (71%).

The new daily bag limit of four Category 1 "high risk" fish species still represents a good day's catch that should meet the expectations of the majority of recreational fishers. This change will also be consistent with the daily bag limit of four Category 1 fish, which was recently introduced for the clients of licensed fishing tour operators operating throughout WA.

The proposed reduction in the daily bag limit for pink snapper from four to two also received a high level of support in submissions (90%).

Implemented Decision: Reduced mixed bag limit for category 1 fish – 4 per person per day. The individual mixed daily bag limit for Category 1 "high risk" fish is reduced from seven to four fish in the West Coast Bioregion.

Implemented Decision: Reduced species bag limit for pink snapper – 2 per person per day. The daily bag limit for pink snapper is reduced from four to two in the West Coast Bioregion.

Abrolhos Islands

The proposal that the finfish possession limit within the Abrolhos Islands Fish and Fish Habitat Protection Area be reduced to 10kg of fillets or 1 day's bag limit of whole fish per person received a high level of support in submissions (81%).

Implemented Decision: Reduced possession limit at Abrolhos Islands. The finfish possession limit within the Abrolhos Islands Fish and Fish Habitat Protection Area is reduced to 10kg of fillets or 1 day's bag limit of whole fish per person – this possession limit can be transported back to the mainland.

Size limits

The proposed increase in the minimum legal size for pink snapper for both recreational and commercial fishers received strong support in submissions (78%). Closer examination of the nature of the commercial fishery in the Midwest and Kalbarri zones indicates that an increase in the legal minimum size could result in a significant level of mortality for released fish. Most of the commercial catches occur in water greater than 90 m depth where mortality issues associated with barotrauma exist for released fish that have been caught on commercial gear. This could negate any benefits of the increased size limit within this region.

Significant reductions have already been achieved in the commercial catch of pink snapper, and further commercial management changes will be implemented early next year. Protection is already in place for spawning aggregations of pink snapper in Cockburn Sound. Consequently an increase in the minimum legal size for pink snapper will apply south of Lancelin only in the southern area of West Coast Bioregion.

Further consideration may be given to increasing the minimum legal size for pink snapper north of Lancelin in the future, depending on further assessment of the impacts of the commercial sector. To assist all fishers in adjusting to the change, the new minimum legal size will be phased in over the next two years, with an initial increase from 41 cm to 45 cm in October 2008 and then from 45 cm to 50 cm in 2010.

Implemented Decision 3: Increased minimum legal size for pink snapper south of Lancelin South of Lancelin, the minimum legal size for pink snapper will be increased from 41 cm to 45 cm in October 2008 and then from 45 cm to 50 cm in 2010.

Boat limits

The proposal to have a boat limit of eight Category 1 fish on recreational boats and a bag limit of two Category 1 fish for the clients of boat-based licensed fishing tour operators received good support in submissions (63%). A significant number of submissions supported changes to licensed fishing tour boat bag limits, but did not support the "fixed" recreational boat limit.

Implemented Decision 4: Boat limit of 8 for Category 1 "high risk" fish
A boat limit of two daily bag limits for Category 1 "high risk" fish will be introduced (*i.e.* eight Category 1 fish) for the West Coast Bioregion. Where five or more fishers are on board a recreational boat or licensed fishing tour, an additional two Category 1 "high risk" fish per person (over and above the boat limit) is permitted for the fifth and additional fishers.

Seasonal fishing restrictions

The proposal to prohibit the catch of the "vulnerable" species (dhufish, pink snapper, baldchin groper, breaksea cod and red snapper/bight redfish) from 15 October – 25 December and then from 1 February – 31 March in the West Coast Bioregion each year received a low level of support in submissions (25%).

However, of those responses that disagreed with the proposal, 27% provided alternative suggestions on the timing and duration of the closure. The principal suggestions were for a three-month closure only and for a closure period from 1 November to 31 January.

It is important to note that the seasonal restriction will not affect beach fishing or boat fishing for species such as squid, whiting, herring, skippy, salmon, tailor or significantly impact on fishing for "pelagic" species such as Spanish mackerel and tuna. This will allow recreational fishers to still go fishing and still catch a wide range of species.

Gear Restrictions

Spearfishing on compressed air

The proposal to prohibit spearfishing of Category 1 "high risk" fish on compressed air in the West Coast Bioregion received 51% support in submissions. Comments received were "polarised" and either strongly in favour, or strongly opposed to the proposal.

Power-assisted fishing reels

To provide additional protection for deep-water species it was recommended that the use of power-assisted fishing reels (*e.g.* electric fishing reels etc) by recreational fishers be prohibited in the West Coast Bioregion, with exemptions provided for fishers with disabilities. A significant number of submissions supported this recommendation (74%).

Fishing competitions

The proposal to initiate discussion with fishing clubs to discourage public fishing competitions in the West Coast Bioregion from including high risk demersal species such as dhufish, pink snapper and baldchin groper in prize categories received a good level of support in submissions (64%). Of those that disagreed a significant number called for the prohibition of any fishing competition that targets at risk demersal fish.

Voluntary Logbooks

The proposal to establish a voluntary catch recording/logbook program received strong support in submissions (86%). Feedback from submissions and stakeholders indicated a strong desire from recreational fishers to be involved in fisheries research programs.

If participation in the voluntary logbook program is found to be insufficient to meet research requirements, consideration will be given to introducing a compulsory logbook program and the development of a recreational fishing registration system in the future

Recreational Fishing Trust Fund

The proposal to establish a recreational fishing trust fund received strong support in submissions (82%). The Fund is to be overseen by a committee consisting of key stakeholders from the recreational fishing sector, with the function of providing advice on recreational fishing funding priorities.

Fish Reserves

The proposal to undertake further research to investigate the appropriateness of establishing large scale fish reserves received 57% support in submissions. Comments raised in submissions included concerns over the justification, location and size of any spatial closure. There are several research projects currently underway which will provide additional information and help determine the appropriateness of introducing large-scale fish reserves in the West Coast Bioregion as an additional strategy to reduce fishing effort and protect the spawning stock. These projects include the Fisheries Research and Development Corporation (FRDC) funded project "Managing and Monitoring of Fish Spawning Aggregations within the West Coast Bioregion of Western Australia" and the Western Australian Marine Science Institute (WAMSI) funded project "Implications of Mobility and Stock Structure of Species for Management Approaches".

These research projects are funded separately from the $5.3 million research project funded by the WA Government that will provide catch monitoring (creel survey) and biological sampling to gauge the effectiveness of the management arrangements and the stock recovery of key demersal fish in the West Coast Bioregion.

The data gathered from this research coupled with the FRDC and WAMSI studies will provide information on the stock structure and egg/larval distribution for species such as dhufish and pink snapper. This information is vital in determining if and where spatial closures could be used, and will help to guide further consultation regarding this issue.

Implemented Decision: Further research the appropriateness of large scale fish reserves. Further research be undertaken to investigate the appropriateness of introducing large scale fish reserves or closed areas to provide protection for large numbers of fish or over an area, which is particularly important to spawning.

8.4 Conclusions

The intent of Objective 4 was to both develop a suite of alternative management scenarios that were understood by stakeholders and to develop models to assess the efficacy of these scenarios. The first part of this objective was achieved through the alignment of the scientific advice flowing from this project and the policy development that considered the Wetline (commercial fishing) and IFM (sectoral allocation) initiatives in the broader context of fisheries management (*e.g.* ESD, commercial viability, angler expectations, passive-user expectations, social and environmental consequences etc.). A shared understanding that developed iteratively over the past several years as the scientific knowledge of the key fish species and complexities of potential management systems became better understood permitted an informed consideration of alternative management measures.

The high level of concern and interest in the sustainability of dhufish and pink snapper by all sectors and the commercial and recreational importance of these species in the WCB have contributed to making it a sensitive and emotional issue for stakeholders. The change from the intended fully integrated stock assessment model to the weight-of-evidence approach utilizing estimates of fishing mortality has not impeded the assessment of alternative management measures, but did require a different approach to assessing the relative contributions of different management measures to the reducing fishing mortality. In hindsight it is apparent that only an iterative approach that allows full consideration of the consequences of the responses to management initiatives will deliver useful outcomes for complex fishery problems.

The Department of Fisheries is continuing to work with stakeholders to formulate policy for managing demersal scalefish in the WCB. The information obtained in this FRDC project will continue to be critical for this process.

9.0 Project summary

9.1 Benefits and adoptions

This project has greatly improved the understanding of the biology of pink snapper and dhufish in WA' s West Coast Bioregion (WCB). Information from this study has been used to undertake stock assessments that have been used in the multi-sectoral management of the exploitation of the demersal scalefish resource in the WCB. The development of appropriate management options for each fishing sector would not have been possible without the information provided by this project.

9.1.1 Commercial fishery

A Management Planning Panel (MPP) was formed to facilitate the development of management arrangements for the commercial sectors that target demersal scalefish in the WCB. Data from this project was provided to the MPP and used in the development of a Total Allowable Effort model for proposed management zones for the commercial wetline sector.

9.1.2 Integrated Fisheries Management

The committee progressing the IFM initiative is the IFAAC (Integrated Fisheries Allocation Advisory Committee). Data from this project was provided to the IFAAC as it became available. Keeping IFAAC abreast of new data during the course of the project was particularly useful as it contributed to the strategies that IFAAC were developing to deal with the allocation of the WCB demersal scalefish resource.

The main beneficiaries of this project are the commercial and recreational fishers and the charter boat operators who target pink snapper, dhufish and other demersal scalefish along the WCB. Fishery scientists, researchers and managers in WA will benefit from the comprehensive information gained about two co-occurring but biologically very different temperate demersal scalefish species.

As this scalefish fishery is the first multispecies fishery in Australia to undergo IFM (*i.e.* a formal process of explicit allocation between sectors), the results of this study and the application of these results in IFM will be useful to other agencies taking an integrated approach to management.

9.2 Further development

9.2.1 Recruitment and spatial dynamics of early life history stages

Because recruitment variability is a key factor that influences the efficacy of management actions, the uncertainty regarding future recruitment strength is a critical concern when designing a management system for the fishing sectors of the WCB.

Dhufish

The potential link between recruitment strength and oceanographic conditions identified in this project suggests that the influence on recruitment may be initiated at the egg and larval stage. Further research should aim to elucidate the relationship between dispersal and production processes associated with such environmental conditions and annual recruitment abundances.

Research is now underway to gain a better understanding of the connectivity between dhufish in different regions, and to examine the strength and behaviour of the Capes Current.

Pink snapper

The two major known spawning sites of pink snapper on the West Coast of Australia are approximately 1000 km apart; one is off Carnarvon in the Gascoyne Bioregion and the three adjacent embayments of Owen Anchorage, Cockburn Sound and Warnbro Sound located in the Metropolitan region of the WCB. This project has shown that pink snapper also spawn outside of the inshore aggregation areas but these fish are generally smaller in size and thus less fecund. A critical uncertainty for the WCB pink snapper stock is whether recruitment throughout the bioregion results from both the Metropolitan and Carnarvon spawning aggregations, and what is the relative contribution of each of these key aggregation sites versus localized spawning events.

Future management of pink snapper stocks will be enhanced by a study that determines the origins of adult pink snapper in regional fisheries using age-related microchemistry of the otoliths, similar to the studies undertaken in South Australia and Victoria (Fowler *et al.* 2005; Hamer *et al.* 2005). Understanding the connectivity between adult stocks of pink snapper throughout the WCB will highlight the importance of the contribution of recruits from such spawning/nursery areas to the west coast pink snapper fishery. Thereby, determining the appropriate the level of protection required to maintain the sustainable exploitation of pink snapper in the WCB.

Further research on the reproductive biology of pink snapper in the WCB should focus on fish in the major spawning areas of Owen Anchorage, Cockburn Sound and Warnbro Sound. Cockburn Sound has the most highly industrialised coastline in the WCB, and many current and proposed developments threaten the ecological environment of this embayment. A better understanding of the spatial and temporal use of Cockburn Sound and surrounds by all life stages of pink snapper is necessary to fully understand the importance of these vulnerable inshore habitats to the Metropolitan pink snapper stock and to the broader west coast pink snapper stock. Protection of pink snapper stocks may involve mitigating or offsetting the impacts of future industrial and urban development in these three adjacent marine embayments. Further monitoring of the temporal and spatial patterns of spawning in these embayments will follow on from data collected since 2001 by Wakefield (Wakefield 2006) and the derivation of batch fecundity estimates will provide data required to estimate the spawning biomass of this stock using the daily egg production method.

9.2.2 Stock assessment and monitoring

Age monitoring

This study indicates that the dhufish and pink snapper stocks in the WCB urgently need management action. The instruments/methods to manage these stocks have yet to be fully developed. Nonetheless, given that fishing mortality (F) is currently the primary metric on which to assess the status of the dhufish and pink snapper stocks, there will need to be an ongoing monitoring program to collect representative and adequate age samples (see Part 1, Wise *et al*., 2007).

Exploitation rates and fishery data

Once the management arrangements for the various sectors have been implemented it may be several years before the WCDSF stabilizes as fishers adjust to any new management arrangements. The application of effort by the fishery (all sectors) during this period, and in the future, may be quite different to current patterns, which will impact on the robustness of the time series of catch and effort data. Part of this problem will be alleviated by further implementation and uptake of the daily logbook system for commercial fishers, while the charter sector already has an established daily logbook system. Careful monitoring of catch and effort of the recreational sector remains more problematic, but current research to investigate cost-effective means to improve the recreational fishing data, particularly the frequency of recreational fishing surveys, is currently underway. A combination of remote sensing of angler participation rates and phone/diary surveys are expected to provide suitably cost-effective, but nonetheless acceptable, time series of recreational catch and effort data.

9.3 Planned outcomes

This project has provided fishery managers with stock assessments and multi-sector catch information for pink snapper and dhufish for three regions within the WCB. The information on the regional differences in the biology of pink snapper and dhufish will be used to underpin management of these fish stocks. Knowledge of spatial dynamics of the fish will aid fishery managers to determine the spatial scales of management within the WCB and to provide an integrated management plan that considers resource sharing among all users.

There were six planned outcomes for this project

Knowledge of the levels of intermixing among regional populations of pink snapper and dhufish to provide advice on the most appropriate spatial scale(s) of management within the WCB (Objective 1). **ACHIEVED**

An understanding of the regional differences in the age structure and biology of pink snapper and dhufish within the WCB (Objective 2). **ACHIEVED**

Advice on stock assessments and multi-sector catch information for pink snapper and dhufish in three regions along the WCB (Objective 3). **ACHIEVED**

Scientific advice to the stakeholders, managers and the independent panels involved in the commercial management process (Objective 4). **ACHIEVED**

That scientific information provided to managers and stakeholders will underpin the development of potential management options for the fishery (Objective 4). **ACHIEVED**.

9.4 Conclusions

Dhufish are long-lived and maximum ages of fish ranged from 24 years in the north to 32 years in the south. The age structure of dhufish was generally unimodal with a mode of 5–12 years and an extended tail of old fish, which is typical of long-lived stocks that have been heavily fished. Stock assessments of dhufish indicate that levels of fishing mortality are high (above threshold and/or limit reference points).

Adult dhufish remain resident within particular geographical locations but there is no evidence for the presence/location of specific nursery areas nor is there any information on the spatial dynamics (*i.e.* movements or lack thereof) of juvenile stages, although this may reflect the low susceptibility of young juveniles to sampling/fishing gear. The initial dispersal of the pelagic eggs and larvae away from spawning locations will be influenced by oceanographic conditions and the swimming ability of larvae. This is most likely the main mode of dispersal for this species.

Dhufish males attain a larger size than females and have very low reproductive investment per individual, which is indicative of a complex social breeding behaviour that minimises competition between males for ripe females. Little is known about the spawning behaviour of dhufish and spawning aggregations appear to be localised events dispersed throughout the species' range.

Dhufish are serial batch spawners that spawn from November to April. Not all mature female dhufish spawn throughout the breeding season. The impact of sperm limitation on the spawning success of dhufish remains to be investigated. The amount of eggs spawned per individual and the frequency of spawning was variable among regions.

Pink snapper are long-lived and maximum ages of sampled fish increased with latitude (ranging from 26 years in the North region to 33 years in the South region). Except in Cockburn Sound where the age composition was dominated by fish between 7 and 13 years of age, the age frequency of the three regions were generally unimodal, with very few fish older than 10 years of age. The stock of pink snapper appears heavily fished with many of the older (*i.e.* > 10 years) fish removed from the population. Given, the limited number of age classes in the age compositions recruitment pulses could not be determined for pink snapper in the WCB. Stock assessments of pink snapper indicate that levels of fishing mortality are high (above limit reference points).

Size at maturity varied regionally and was smaller in the North region than the Metropolitan region. Size at maturity in these regions was greater than the legal minimum length indicating that some pink snapper are being removed from the fishery before they are able to spawn. The timing of spawning varied along the coast and ranged from July to September in the North region, to October to January in the South region, and was highly correlated with water temperature. If the spatial dynamics of pink snapper are similar to elsewhere in temperate Australia, The main mode of dispersal is likely to be movement of sub-adult fish, *i.e.* from nursery areas at ages > 18 months and prior to maturation.

The weight-of-evidence approach (Wise *et al*., 2007) to stock assessments for pink snapper and dhufish made use of all the available data. These assessments indicate that the levels of fishing mortality being experienced by both stocks are well above optimum levels for the sustainable exploitation of these key target species. The Department of Fisheries, Western Australia will continue to liaise with stakeholders to investigate the most appropriate way to manage the pink snapper and dhufish stocks in the WCB in order to alleviate the high fishing pressure while also attempting to balance the economic and social values of the WCDSF.

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11.0 Appendices

Appendix 1. Community Consultation desk top study

Community consultation

Introduction

Significant changes to management of demersal finfish stocks within the West Coast Bio-region are underway in response to critical levels of fishing pressure. Central to these changes will be estimates of sustainable catch levels, particularly for the two key exploited species within this region, WA dhufish and snapper. An important objective of FRDC Project 2003/052 is to engage with recreational fishers in a series of public meetings to exchange information and ideas so that the most effective and acceptable management strategy for the West Coast finfish fishery can be developed. The purpose of this document is to identify issues and procedures relevant to the proposed community consultation strategy.

Community Consultation

Why?

Most fisheries problems arise from a failure to understand and manage fishers (Hilborn & Walters 1992). Consultation with fishers and other stakeholders is recognised as essential for a holistic view of a fishery, by providing feed-back to management and allowing integration of fisher preferences into the fisheries management process (Sissenwine & Mace 2003). This is also being driven by stakeholder expectations of more open communication and greater involvement in the decision-making process, which in turn results in wider acceptance of management strategies.

How?

Consultation with the commercial sector is well advanced as part of the wetline review for the West Coast Bioregion. The consultative process detailed here is therefore focussed on the recreational sector, although commercial fishing representatives will be asked to participate.

As outlined in the FRDC proposal, community consultation will be made via a series of workshops. Common methods of collecting recreational fishing information, such as mail, telephone and creel surveys are therefore not considered here. The exchange of information within the workshop series will include a survey to gather the required data from recreational anglers.

The following points are relevant to this desktop study of the community consultation process:

- The objective of the meeting
- Timing and location of workshops.
- Identification and notification of participants.
- Workshop processes
- DoF presentations

These points are discussed in detail below:

Meeting objectives

The objectives of each series of meetings will change as the project develops.

Timing and location of workshops.

As detailed in the FRDC proposal, workshops will be held at three locations within the West Coast Bio-region (twice yearly). These locations will be Geraldton, Perth and Busselton so that a broad range of people within the Bio-region are consulted. Specific locations are yet to be decided, but where possible the workshops will be held at Department of Fisheries premises. Final choice of location will depend on the number of participants and suitability of the venue.

Each workshop will run for about 2-3 hours commencing about 6-7 at night during the week. This should be the most convenient time for working people, and not be too long that people are reluctant to participate. At the end of each workshop the schedule for the next shall be arranged in collaboration with workshop attendees.

Identification and notification of participants

DoF staff

Staff will vary depending on the objective of the meeting. Chairperson, management representative, scientists (who will give talks about the project and research), 2 x assistants (data collecting, tea and biscuit providers etc).

Public

Key points:

who are the target population
how many participants to invite?

A broad spectrum of participants will be invited to attend in order to avoid biases in results. Bryan (1977) outlined 4 types of anglers according to their level of specialisation, based on the activity's meaning to individuals and their behaviour:

Occasional anglers
Generalists
Technique specialists
Technique-setting specialists

These specialisation levels were reflected in such phenomena as amount of participation, setting preferences, technique preferences, choice of equipment, importance of catch, social setting of the activity, and preference for management measures. Segmentation of the angler population by catch preference, experience and participation can help fishery managers understand diversity in consumptive preferences and attitudes among anglers. Estimates of the size and demand of angler groups can also provide an understanding of the relative demand for the different types of fishing experiences sought (Fisher 1997).

Other subgroups to be considered include:

non-fishing aquatic users
indigenous fishers

Commercial fishing representatives will also be invited to attend.

If the survey is to accurately reflect the general population's opinions it is essential that the percentage of each subgroup in the survey reflect their percentages in the general population (http://www.surveysystem.com/sdesign.htm).

The workshop forum will also impose limits on the number of participants that can be invited. This is an important issue in terms of relevance and acceptance of consultative outcomes, and will require further discussion amongst program leaders and statisticians.

Once the desired types and numbers have been determined the next step is contacting potential participants.

Appendix 2. Stakeholder meetings

First series of stakeholder meetings

The first series of the stakeholder meetings was undertaken in the period 30 June to 14 July. Meetings were held in Busselton, Geraldton and Perth. Dr Dan Gaughan, Dr Michael Mackie from the Department's Research Division and Mr Andrew Rowland from Recfishwest each gave a presentation. The speakers provided a background to the biology of the icon species, an outline of the project and the need for community participation in helping the investigators successfully conclude the project and were facilitate by Ms Cathy Campbell, the Community Engagement and Stakeholder Relations Officer from the Department's Corporate and Community Relations Branch.

Questions were taken from members of the audience at the conclusion of the three sessions. Table 1 provides a summary of the three meetings. An example of the flier and feedback form distributed to participants at each meeting are at the end of this Appendix.

Table 1. Meeting statistics.

	Busselton	Geraldton	Perth
Date	30 June	7 July	14 July
Venue	Broadwater Beach Resort	African Reef Resort	Aquarium of Western Australia
No of participants	40	43	26
No of feedback forms submitted	11	16	14
Feedback statistics			
Expressed of interest in attending a similar seminar	5	14	12
Recreational fisher	10	12	12
Commercial fisher			1
VFLO		1	1
Aquaculture interests	1	4	7
Environmental interests	2	5	7
General interest in fisheries			7
Other		Fisheries Officer Sea bird researcher	1 research student 1 post graduate student 1 Murdoch University Lecturer
Media newspaper articles	Busselton-Dunsborough Mail 30/6/04 pp 5,8	Midwest Mail 22/7/04 pg 25	The Sunday Times 11/7/04 pg 60
Media advertising placements	Busselton Margaret Times 26/6/04 pg 6 Bunbury Mail 23/6/04 pg 14	Midwest Times 30/6/04 pg 31 Geraldton Guardian 2/7/04 pg 36	The West Australian 2/7/04 "Fishing" pg 10 The West Australian 9/7/04 "Fishing" pg 11

Benefits of the first series of meetings

Increased profile of fisheries research work

Increased stakeholder and community awareness of important issues with respect to dhufish and snapper populations

Increased awareness of the impacts of fishing

Face to face communication between staff and the general community

Improved stakeholder interaction and relationships

Information exchange

Access to contact details of individuals interested in assisting with the research effort on the project (facilitate collection of fish specimens from recreational fishers)

Highlighted impact of different mediums for promoting fisheries events

Generated options for improving advertising strategies

Second Series of stakeholder meetings

The second series of the stakeholder meetings was undertaken in the period 1 December to 11 September. The aim of this series of meeting was to provide an update on the overall results of the research project and more detailed information about the particular region where the talk was held. Questions were taken from members of the audience at the conclusion of each talk. Meetings were held in Busselton and Geraldton during December 2004 and presentations were given by Dr Dan Gaughan, Dr Michael Mackie and Dr Jill StJohn from the Department's Research Division and Mr Andrew Rowland from Recfishwest. Despite contacting all past participants, who had left their names and addresses when attending the first meeting series, and spending nearly $1000 in advertising in local newspapers, there was a low turn out to the regional meetings. This may be due, in part, to the timing of the meetings close to the festive season. Because of the low turn out at the regional meetings, we decided to hold the Perth meeting in conjunction with another meeting aimed as a follow up from the Samson Science project. Although this meeting was held later than originally anticipated, the benefits included using the new public facilities at the Department of Fisheries, widespread publicity and a range of speakers from Department of Fisheries, local universities and Bill Sawynok from the National Release Fishing Strategy. About 75 people attended the Perth meeting (see Table 2 for a summary of the three meetings).

The feedback was positive from all three meetings and stakeholders were very keen to learn more about the research done.

Table 2. Meeting statistics.

	Busselton	Geraldton	Perth
Date	7 December 2004	13 December 2004	11 September 2005
Venue	Broadwater Beach Resort	African Reef Resort	Western Australian Fisheries and Marine Laboratory
No of participants	<10	<10	75
Media advertising placements	The West Australian 8/12/04 “Boating” pg 29	Midwest Times “Public Notices” 8/12/04 pg 29 Geraldton Guardian “Public Notices” 10/12/04	No paid advertising was required. Media release taken up by all the local papers

Example flier provided at the meetings

Thank you for participating in the Department of Fisheries seminar on dhufish and snapper research in the West Coast Bioregion.

Tonight

Department of Fisheries scientists Dr Dan Gaughan will provide an introduction to the research on dhufish and snapper currently underway and overview of the objectives of a Fisheries Research and Development Project (FRDC) on these species. Dr Michael Mackie will follow with the background to a new FRDC project on Samson fish and Andrew Rowland from Recfishwest will speak about his catch and release studies.

You will hear about what is known and not known about dhufish and snapper on the west coast and how you can assist the Department in gathering information to improve our knowledge of these stocks and of the samson fish in metropolitan waters.

Questions

Questions relating to dhufish, snapper and samson fish presentations will be taken at the conclusion of the three talks.

If you have any questions about other species please jot them down on the attached form and hand the form to the Chair at the end of the seminar. Your questions will then be directed to the appropriate person in the Department.

Feedback

We would like to hear what you think about tonight’s presentation and how it has been organised. A feedback form is included in your papers for this purpose and will be collected at the end of the night.

Feedback form for the dhufish and snapper seminar

This questionnaire is designed to determine how effective the seminar has been for you, and how we might improve further seminars.

How did you learn about this seminar?

Are you a

- ☐ Recreational fisher
- ☐ Commercial fisher
- ☐ Interested in fisheries in general
- ☐ Interested in the environment
- ☐ Other (please specify)

Are you part of an organisation that is interested in the state of Western Australia's fisheries? YES/NO

If yes, what is the name of your organisation?

What are the contact details of your organisation?

<u>Instructions for next four questions</u>

Please circle the appropriate rating for each question:

1-Strongly Agree **2**-Agree **3**-Neutral **4**-Disagree **5**-Strongly Disagree **UJ**-Unable to Judge

1. The seminar covered the material that I expected.	**1 2 3 4 5 UJ**
2. The information presented was easy to understand and instructive.	**1 2 3 4 5 UJ**
3. a) 6:00pm – 8:00pm is a good time for an event of this kind b) If 6:00 -- 8:00 pm is not a good time, what time would you prefer?	**1 2 3 4 5 UJ**
4. The venue was suited this type of event	**1 2 3 4 5 UJ**

Please comment on what you thought were the best aspects of the seminar.

Would you like to attend a workshop within the next six months to assist the Department's research on snapper and dhufish stocks? YES/NO

If yes, please state your name and contact details

What other topics would you like to hear about through a seminar?

What other questions relating to fishing can we answer for you? Please provide your name and mailing address so our response will find you

Any further comments, criticisms or suggestions? Please use the back of this page for further comment

THANK YOU FOR YOUR HELP

Appendix 3. Petition to the minister

Downloaded from the WANGLER website on 27/7/06

Dear Fisheries/ Minister/ Premier/ Minister for tourism/Recfishwest

We the undersigned, as a small but highly informed group of recreational fishers, believe that the West Australian Jewfish (as well as many other highly sought after demersal species in the metropolitan area), are under immense pressure from both the commercial and recreational sectors. With the recent spike in population growth in this state and the increased efficiency of fishing methods, it is obvious that this pressure will continue to grow to worrying levels despite the use of traditional fisheries tools.

We urge the government and fisheries to urgently implement a plan to manage this fishery with precaution while IFM proceeds in due course.

We believe that any one (or a combination) of the below could only improve and protect the fishery. First, foremost and above all else we recommend

1. The immediate implementation of the Zone 5 (i.e. metropolitan region) concept

We are also willing to consider the following:

2. Time-limited rolling benthic protection/Fish habitat and protection corridors/ trolling only areas.
3. A time limited closure to all stakeholders for specific species under threat.
4. A limited tag-issue system for the commercial and recreational sectors.
5. Permanent benthic protection/Fish habitat and protection corridors/ trolling only areas.*

Such precautionary measures should be coupled with a far higher research budget for both the jewfish and other heavily fished demersals so that the fishery for these fish, with particular reference to the endemic and iconic West Australian Jewfish (*Glaucosoma hebraicum*), can continue at a healthy and sustainable level into the future.

We realise that something of this magnitude takes time but we hope you are much further along this track than we are.

These are just five ideas. We urge you to do something.

Sign here

55 Signatures inserted 26/7/2006

Appendix 4. Draft Management Proposals for the Metropolitan Recreational Fishery

Draft Management Proposals for the Metropolitan Recreational Fishery

By Garry Lilley & Wally Parkin

August 2005

Introduction

Cumulative pressure on the metropolitan fishery increases daily as a result of Perth's expanding population. The metropolitan fishery is generally considered to extend from Two Rocks in the North to Dawesville in the South.

This paper recognises that increasing fishing pressure applied to this region, by all sectors, will require some new management initiatives to sustain it and take it forward over the next 50 years. It is our duty as responsible fishers to ensure a healthy, sustainable fishery is available for future generations, and it is the intent of this paper to put forward management concepts that can deliver this.

The metropolitan fishery is part of the West Coast Bioregion that extends from Kalbarri in the North to Augusta in the South. It is recognised that a large portion of the State's fishing activity occurs in this zone and is centred around the metropolitan area. We therefore believe it is imperative that the management for this fishery recognises this salient fact and is accordingly managed at a higher, more stringent level. In order to achieve this the metropolitan waters should be managed as a zone within the West Coast Bioregion.

Continuing advances in fishing technology, for both sectors, equipped with faster longer range vessels means that the fishing efficiency of both fleets has reached new levels. This paper recognises that many of the significant technological improvements in fishing practises have occurred over the last ten years. The metropolitan fishery cannot possibly withstand the cumulative increase in effort that is occurring, in addition to increased fishing efficiencies, and this paper identifies some of the major issues and puts forward some solutions based upon common sense and co-operation between both fishing sectors and Government.

Serial depletion is already taking place in the Metropolitan fishery. Where once charter operators and commercial operators fished waters up to 50m in depth they are often fishing past Rottnest in water depths of over 100m. Previously this water depth provided respite for some species that have inshore/offshore movements, but no longer. Both sectors are now starting to encounter previously unheard of species like the hapuka, grey banded cod and several other species for which we have absolutely no research data. It is likely that many of these deep water species are vulnerable eg. *hapuka stocks are not considered resilient with a minimum population doubling time of 14 years* (Fishbase website).

Inshore species that have been heavily impacted in the metropolitan waters include the blue groper, baldchin groper, and the iconic Western Australian dhufish.

Blue Groper are now rarely found in the metropolitan waters, even though they were prolific only 30 years ago .The Western Australian dhufish is the most sought after and prized species for both sectors. This species is under threat and documented in many of the Department of Fisheries reports from the previous 10 years. The lack of big breeding stock for this slow growing species especially with females is very concerning and maybe heading the same way as the Blue Groper. Many species including the ones mentioned through this region can not withstand this kind of fishing pressure for much longer without stricter management controls (Stages)[*we need the correct scientific current assessment to go inhere. You shouldn't just use broad sweeping statements as they will open the paper to criticism* (Stages)].

Research Required

Given the recently identified biological differences identified in dhufish it is imperative adaptive management strategies for this fishery are introduced ahead of Integrated Fisheries

Management. Concessions will need to be made by both sectors as a priority as short-term economic benefit will inevitably result in tighter management controls being applied in the future. It would seem far more responsible to offer up some responsible options now rather that wait until both sectors are squabbling over what's left. The fishery must be brought back to sustainable levels within a reasonable time-frame.

The Fisheries management framework, of the 21st century must not only be able to manage the level of exploitation by commercial and recreational fisheries, But also provide and agreed basis and process for changes in the way fish and aquatic resources are used and shared by this community There is a clear need to counter inevitable pressure on stocks from the impact of a growing population, increasing coastal development and the demands of various key user groups. Unless we are proactive in dealing the growing exploitation of fisheries along our states vast 12,000km coast line, it will be difficult to sustain it for the future.

(Protecting and sharing Western Australia's coastal fish resources. The path to Integrated Management – FMP 135)

ZONE 5 The Metropolitan Bioregion

Zone 5 is a proposed management strategy that will ensure a healthy fishery that all fishing sectors and the wider community can enjoy over the next 50 years.

For the purposes of this paper metropolitan waters extend from Two Rocks in the North to Dawesville in the South, out to the 200m isobath and includes all rivers, estuaries and lakes in the catchment.

These management proposals encompass a range of recommendations for all species and user groups. Recreational Fisherman. Commercial Sector. Indigenous groups the general public and the State Government of Western Australia.

Recommendations For Zone 5

Initiatives from the recreational sector;

1) Cockburn Sound pink snapper closure to extend to whole of Zone 5 during the period set by the Department of Fisheries in the new management plan for the species to be announced soon.

2) Pink snapper minimum legal size increased to 450mm immediately for all sectors. More research needs to be applied for this species. It is widely known that Cockburn/Warnbro sounds are the only breeding/spawning grounds for this species in this region, and maybe others. There for we have no data to confirm that the Pink Snapper caught out of these spawning grounds are not the future spawning fish for this region. A precautionary principle approach should be applied.

3) Determine whether FHPAs would be an effective management tool in sustaining slow growing residential demersal species in Zone 5. An example would be in the likes of a 3 nautical mile no take zone around Rottnest. But still allow shore based angling and trolling for pelagic species within the 3 nautical miles .This would protect the demersal species. And still allow recreational fisherman to target different species without having little or no impact on the slow growing dermersal species.

Recent data released on the effectiveness of MPA's at the Abrolhos islands indicates a significant benefit to resident species such as Coral Trout. there is know evidence to suggest this strategy would not be successful for species such as West Australian Jewfish and Break sea Cod. The Westag Tagging program is showing that West Australian Jewfish are residential, especially with younger or smaller sizes of this species

4) Maximum legal size of Western Australian Jewfish to be 850mm for all sectors.

Research needed here

How important such females can be is illustrated by the example of a single ripe Female red snapper, Lutjanus campechanus, of 61 cm and 12.5 kg, which contains the same number of eggs (9,300,000) as 212 females of 42 cm and 1.1 kg each

(The Fisheries Centre, British Columbia Canada)

5) Ban drag-netting in all estuaries in Zone 5. Bycatch is a major issue especially in the Peel/Harvey Inlets that this measure would combat. Since the early nineties the Swan River Prawn has been nonexistent and environmental impacts have severely reduced this species in numbers, Therefore it is recommended that participating in this practice is having more of an environmental impact on other species in the means of by catch for very little or no reward of Swan River Prawns.

6) No recreational gillnetting allowed in Zone 5

7) Reduce the Category 1 mixed daily bag limit from seven down to four, These Species are generally long-lived, slow growing, mature at four years plus. form semi-resident populations, are vulnerable to localized depletion due to their life history, or are of low abundance or highly targeted.

This is becoming more and more apparent where the fishing pressure is applied in the most populated metropolitan area, mainly due to the fact that category 1 fish are generally the highest quality for consumption. There for, it is suggested that the category 1 fish limit to be reduced to 4, which is ample enough for one person or a family to consume. High grading with this category may be an issue, so compliance laws would have to be sufficient to deter fisherman from participating in this practice. *i.e.* confiscation laws. Hefty fines.

Research needed here

8) Category 3 fish, 20 per species and a combined bag limit of 40.This category includes the species that are highly targeted by recreational fisherman ,Australian Herring, Garfish, Sand Whiting and the like. Most responsible recreational fisherman wouldn't dare take 40 of any of these species, opting to take enough for a feed only (20) fishing for the future.

Research needed

9) Increase the minimum size of the blue swimmer crab to 130mm across carapace Further reductions in bag limits may need to be implemented pending further stock analysis.

Data from the volunteer fisheries liaison officer monitoring program in 1997 reaffirms that crabs are the main recreational targeted crustacean species.

Quote Data from the volunteer fisheries liaison officer monitoring program in 1997

10) Increase King George whiting minimum size to 350mm so this species has at least spawned once to help with future recruitments. Taking any species from the environment to please a select few(recreational fisherman) when they haven't had a chance to spawn is not sustainable management, The current minimum size limit stands at 280mm well before the age of a spawning female.

King George whiting: The age of King George whiting at first capture is 2+ to 3+ years at approximately 250 mm length. The length at 50% maturity is 413 mm for females. King George whiting breed in the open ocean at age 4+, and juveniles use estuaries and coastal waters as nursery habitats for the first few years of their life. Although the legal minimum length is considerably less than the size at maturity, a downward adjustment in the number of commercial fishers in estuaries and coastal waters is likely to have reduced the inshore fishing pressure on this stock. However, targeted recreational fishing for these fish will need to be monitored to ensure overall fishing mortality does not reduce breeding stocks below safe limits

Source State of fisheries report 2003 /04

11) Maximum legal size of black bream to be 400mm in Zone 5 to protect mature spawning fish. Environmental changes have taken its toll on this species over the past 10 years, with fish kills in the Swan /Canning/Murray/Serpentine rivers becoming an all too worrying occurrence each year. It is there for recommended for the no take of this species during spawning times to help balance the natural/unnatural changes that are frequently occurring and hindering recruitments for this species.

Size

A 2.98kg specimen was taken in the Swan River in 1998 but black bream are reported to attain 4kg, and that's an absolute monster. A 1kg bream is a good fish for most anglers and a 2kg specimen is a thumper. Recreational and commercial fishing tends to keep the average size down in our estuary systems. Interestingly the largest black bream netted by Murdoch University researchers in the Swan River during research work was a 2.29kg female, 48.5cm long and aged at 21 years.

Breeding and migration

Spawning normally occurs between November and January in most south-west estuaries and the Swan. Black bream are multiple spawners, which means they release eggs on more than one occasion during a spawning season. Females can release between 96,000 and in excess of 7,000,000 eggs in a season, depending on the size of the fish, which is why keeping good numbers of big bream in our rivers is vital.

Source Western Angler fish identity

13) A total ban of take of cobbler in the Swan & Canning Rivers until this species recovers to acceptable agreed levels. Bag & Size limits and fishing methods were reviewed in 1994 to protect and hopefully boost breeding stocks. Since the new management controls in 1994 the biomass of this species in the Swan & Canning systems haven't boosted levels at all, and are still a major concern. This may also be caused through environmental changes and this species needs further protection.

In recent years commercial catches of cobbler have declined dramatically, and large breeding-size fish are making rarer appearances in recreational catches. Cobbler usually reach maturity around 3 years, when they are just over 400mm long, but in past years many where caught before they spawned.

Source Fisheries Department of Western Australia. Cobbler at risk

14) All recreational fisherman, traveling offshore carrying an EPIRB must also equip the boat with a release weight to ensure a higher % of survival rate for undersize or unwanted fish.

There is compelling scientific evidence to suggest the release weight method is a far superior method of releasing demersal fish suffering from barotraumas. quoted by Fisheries WA at the Dhufish Workshop held in June 2004

Source Westag program injunction with ANSAWA and Fisheries WA

15) A Recreational fishing license to be implemented for Zone 5 to fund research, management and compliance

The overall consensus in the recreational fishing community is, they would adopt this approach, providing it was based on a Recreational Fishing License Trust, and wasn't directed back into state government revenue. Where a board/committee was set up to represent recreational fisherman on where money collected from the Trust was allocated, Therefore benefiting their favorite pastime and the benefit of our fishery. Based on the NSW Recreational Fishing LicenceTrust Scheme.

Specific licences for recreational fishing activities have mainly been used to improve compliance with rules for high value species, but have also increased community awareness of fishing rules and resource conservation, and assisted with the collection of research information. Licences also provide some revenue towards management cost for the recreational fishing sector and fish stocking programs for freshwater fisheries.

(Protecting and sharing Western Australia's coastal fish resources. The Path to Integrated Management – FMP 135)

16) Failing this a pre-purchased category 1 finfish tags should be introduced.

This would benefit research in the way of data on captured numbers and participation of recreational anglers targeting prized species in the category 1 class.

It is therefore essential that the question of securing adequate funding for ongoing research, education and management is the subject of widespread community consideration and debate. Fresh ideas on alternative financial strategies and new funding sources will be welcome.

(Protecting and Sharing Western Australia's Coastal Fish Resources The Path to Integrated Management – FMP 135)

17) Compulsory log book system for all recreational fishers in Zone 5 to provide accurate catch data for researchers and management. This is also recommended to assist with the future management plan FMP 135 to ensure when the recreational sector has reached its TAC or allocation quota.

The commercial sector and Fishing Charter fleet already record their catch by law. This gives fisheries researcher's data that is used for a sustainable fishery for all user groups. It is therefore recommended that recreational fisherman be obligated by law to provide the same data for a more accurate assessment of the total overall take from the resource.

The log book should be in the form of a signed statuary declaration that is submitted either electronically or by mail every quarter and made public knowledge. Log books should also be filled out with current catch. *i.e.* before retrieving boat from ramp or leaving fishing place, so compliance officers can cross check with catch and log books, to ensure the participant has entered their data correctly.

Category 1 fish should be measured for total length and species recorded. Category 2/ 3 fish to be recorded by species only.

Despite these shortcomings, and often only with poor quality data, scientists and managers did have access to long time series of commercial catch and effort data to enable determination of the status of exploited target species, and access to a commercial catch from which to gather regular and representative biological samples. However the demise of many of these fisheries as the result of voluntary 'buy-back' of commercial access has rendered these catch and effort data sets far less useful for assessing the status of these stocks today. This means that there is now a far greater reliance on the recreational sector and/or independent surveys to provide the data that is needed to satisfy the reporting needs of Ecologically Sustainable Development

Source. Historical fishery attributes and changing management expectations – a mismatch? R.C. Lenanton

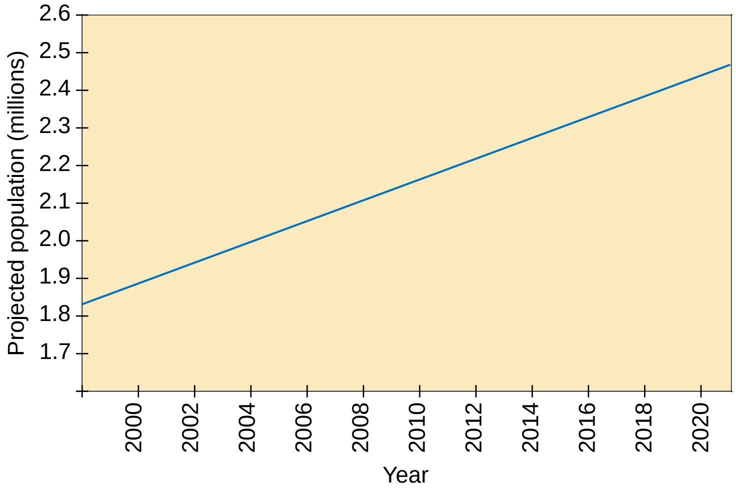
The allocation of fish resources between users is a difficult task. The task is made more difficult by a lack of definitive information on the abundance of many coastal fish stocks and natural environmental variations. In addition, a lack of time series data on the recreational fishery, and uncertainty around the level of accuracy in commercial fishing returns, also means that scientific research can't not provide a robust analysis of actual resource shares.

(Protecting and Sharing Western Australia's Coastal Fish Resources The Path to Integrated Management – FMP 135)

Figures and Tables

Figure 7: Trends in recreational fishing participation rate and fishing effort against predicted population growth 1987 - 2020.

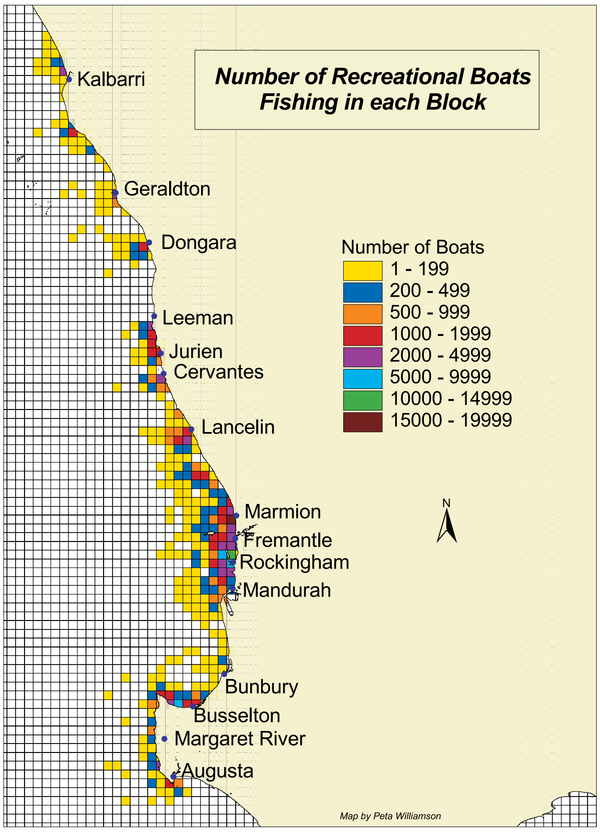
Figure 7(a): Population projection for Western Australia (ABS Series II).



References: Australian Bureau of Statistics (1998). Population Projections 1997 - 2051.

WEST COAST REGIONAL REVIEW

APPENDIX A



88 Recreational Fishing on the West Coast

Initiatives from the commercial sector

1) Immediate suspension of all commercial demersal finfish take in Zone 5 until the fishery has recovered to agreed levels. But still allow a recreational bag limit for personal consumption. All new proposed rules/ regulations must apply to commercial licence holders wishing to participate as recreational anglers.

2) No commercial take of tuna or billfish in Zone 5.

3) Immediate suspension of all Swan River/Canning River commercial crabbing /gillnetting including the wet licence in Cockburn Sound as recommended in the Labor Governments Election Policy 2005

Initiatives from charter vessels

1) The total take on Fishing Tour Operators for a days fishing needs to be seriously addressed. Personal Recreational fishing Bag limits should not apply on a fishing tour. Bag limits for a group of recreational fisherman fishing off one vessel should be restricted by number of fishers on board a Fishing tour. *i.e.* **This is an example only**

Number of People in Boat	*Number of bag limits in boat limit.*
1-2	1
3-4	2
5 – 9	3
10 - 16	4
17 – 25	5

2) All charter vessels must carry and use a release weight.

3) No new Fishing Tour Operator licenses to be issued in Zone 5, and existing licenses to be rationalized.

There is now a moratorium on the issue of any further fishing tour licences in fully exploited fisheries until there is sufficient data for an assessment of the sectors relative impact on the states fish stocks.

(State Of fisheries Report 2002/03)

4) Only one Fishing tour operation within a 24 hour period in Zone 5 (0001am-2359pm)

Recommendations to the government of Western Australia

1) Undertake <u>serious</u> evaluation of stocking fresh/salt water impoundments to take pressure off wild fisheries. This will need to include translocation of eastern state species *i.e.* Murray cod, Golden Perch and Australian bass. Evidence now indicates that this has already happened in an unmanaged way.

NSW / VIC and QLD have embraced this concept in a managed way from small dams to large bodies of water that include water catchments/ lakes and private dams (NSW has 96). These impoundments are attracting Recreational Fisherman from around the country and the world. Thus creating regional employment and economic activity

2) State government to buyout all existing river and estuarine commercial net licenses in Zone 5

In 1996 the Western Australian government set aside $8M over 4 years for a resource sharing initiative, in line with the 1996 coalition fisheries policy. By the end of August 1999 the process had bought out 46 commercial fishing licenses at a cost of $3.2M and successfully removed both real and latent commercial effort in may targeted fisheries these included 3 from the Swan River estuarine system and 9 from the Mandurah system. However, given the potential ability of remaining commercial operators to increase their catches the simple removal of some commercial fishing licenses in these areas may not ultimately make a larger share of the resource available to the recreational sector, and will need to be complemented by other measures to ensure a reduction in total commercial catch over time.

Source (Protecting and Sharing Western Australia's Coastal Fish Resources. The path to Integrated Management – FMP 135)

3) Establish artificial reefs by way of environmentally sound wrecks in inshore waters and off shore waters deeper than 100 meters of Zone 5. *Recfishwest is has ongoing efforts to obtain HMAS Orion for this purpose.*

4) Actively promote catch and release fisheries and low impact eco-tourism in Zone 5

5) All non-listed deepwater species to be classed as Category 1 immediately. This would include hapuka, blue eyed trevella, grey banded cod etc. Other non-listed species such as western fox fish also needs to be placed in the Category 2 class, due to initial data showing these species maybe long lived.

6) Compliance is a key issue for management. Raising fines substantially for non-compliance and rigorously applying confiscation laws already in place will ensure most people adhere to the regulations. Monies collected from illegal activities to fund more fisheries compliance officers.

Conclusion

There can be no argument that the metropolitan waters are under increasing pressure from all sectors, with corresponding impacts on many target species.

The Metropolitan fishery needs management/Government to seriously consider implementing a zone for this bioregion.

This draft proposal is open for serious debate and comment. The issue is more the concept of a Zone for the metropolitan waters that would provide a sustainable fishery for the metropolitan waters for the foreseeable future.

Appendix 5. Preliminary development of a management strategy evaluation model

A series of 5 meetings (04/03/04, 16/08/04, 14/01/05, 01/08/05, 18/10/2006) were held with Associate Professor Norm Hall regarding the development of a model that could be used to assess alternative management scenarios for demersal scalefish in the West Coast Bioregion. Draft specifications for the dhufish and snapper models written by Norm Hall are provided here. Although this model was not implemented, it nonetheless provides a summary of the outcomes of the meetings.

Draft specifications for the dhufish and snapper models

The following draft requires considerable input and revision to ensure that it provides a description of the model that the fishery biologists/managers would like to see developed. A textual description has been developed rather than a mathematical description, to ensure that there are no barriers to communication and that model specification is in the hands of the biologists who know the species and fisheries rather than constrained by the equations developed by a mathematician.

Note that, in modeling a system, we attempt to produce a simplified representation of reality in order that a model can be developed that can work with the data that are available and that can be implemented as a computer program which performs the necessary calculations within an appropriate time frame. Abstraction is a necessity as we cannot hope to develop a model that is as complex as the real system. Thus, in specifying the model, simplifying assumptions should be made if it is likely that these assumptions will not affect the outputs of the model greatly. It should also be noted that model development usually starts with a relatively simple model, adding complexity only after the simpler model has been adequately explored and its behaviour and results understood. Similarly, the model should be composed of modules or components, each of which can be exchanged easily with an alternative representation of that component, thereby allowing enhancement as model complexity is increased or as new knowledge becomes available and also allowing exploration of the sensitivity of model outputs to alternative assumptions.

Models for the dhufish and snapper stocks have been developed. These models represent "operating models", rather than models that are fitted to available data. That is, the models provide a representation of current knowledge of the biology and population dynamics of each species and its relationship with the fishery. The models have allowed exploration of the impacts and effectiveness of alternative management strategies and of the sensitivity of predictions to alternative assumptions or uncertainties. Specifically, the dhufish and snapper models were used to explore various patterns of temporal and spatial closure, reductions in fishing mortality, changes to legal minimum and maximum size, and closures when TACs are reached by commercial or recreational fishing sectors. Indicator variables output by the model include egg production indices, recruitment levels, biomass available to fishers (*i.e*, vulnerable biomass within the size slot available to fishers), average catch per unit of effort by each fishing sector, and the total annual yield taken by each sector.

The depth-structured, regional model for each of these species was developed for an intended audience of fishers from the commercial and recreational sectors, and the general public. However, it also produces output that is of value to the fisheries scientist and/or fishery manager. The user interface is of sufficiently flexibility and simplicity that it can readily be understood by a general audience of fishers. Packaged scenarios, which have been considered by fisheries scientists, driven by alternative model inputs are available for selection by the user. Graphical output is produced when the model is run with each new set of inputs, and the results of the run are stored such that they may be compared (either graphically or analytically) with the results from other sets of input parameters.

The model that was developed to represent each of the dhufish and snapper stocks is of a discrete, spatial, age- and sex-structured form. The stock is distributed over *D* depth zones within each of three regions, *i.e.,* northern, middle and southern regions, and the model tracks the number of fish of each sex and age within each of these depth zones and regions. Note that, to simplify model development and to provide a tool for exploration of alternative input parameters, the model was first developed as a site model, *i.e.* a model for a single depth zone and region, for which no interaction with other depths or regions was considered. Thus, the site model represents a single-area, age-structured model for the species.

The maximum age considered in the model for the species is *A* years, where this last age class is considered to be a "plus group", *i.e* it includes fish of age *A* and older. Time is simulated in the model as a continuum, where the system state is evaluated at weekly intervals, *i.e.* the model time step is 1 week. The initial number of fish of each age and sex, present within each depth zone and region, is calculated to represent the initial system state (derived by assuming that the stock is at equilibrium under the specified levels of exploitation). The model then steps through time, week by week, carrying out the calculations for each time step in three separate phase. These represent the calculations for each area associated with the discrete events at the start of each week, the calculations required to represent the continuous processes operating throughout the week, and finally the calculations required to represent the discrete events occurring at the end of the week. To simplify the model, some processes that are known to be continuous, *e.g.* migration, are represented as discrete events, *i.e.* "discretised". The discrete events at the start of the week, in order of calculation, are (1) spawning and (2) recruitment. The continuous events are fishing and natural mortality. Although differential equations could be solved by the model to update the system state using, say, a Runga-Kutta algorithm, the calculations for these continuous processes will use analytical equations such as the Baranov catch equation and survival calculated as an exponential function of total mortality. The discrete events at the end of the week, in order, are (3) ageing by 1 week and (4) migration. While most events involve only the fish within the specific depth zone and region under consideration, the calculations for migration will be undertaken in two steps, firstly calculating the number of fish of each age and sex that will move from each depth zone and region to each other depth zone and region, followed by the actual movement of those fish.

The framework of this model, as implemented in Visual Basic, takes the form shown below:

```
Sub Model()

    ‘ Set the model’s time clock to 0 weeks and set up
    ‘ the initial number of fish in each sex and age class
    ‘ in each depth zone and region.
    ModelTime = 0
    Call SetUpInitialSystemState

‘ Now loop over time
Do

    ‘ If the week is specified in tables provided by
```

```
    ‘ the biologists as one in which spawning
    ‘ occurs, for specific depth zones and regions,
    ‘ calculate the index of egg production, combining
    ‘ appropriately over the depth zones and regions,
    ‘ as specified by the biologists.
Call SpawnTheFish

    ‘ Use the appropriate stock-recruitment relationship(s),
    ‘ as specified by the biologists, to determine the
    ‘ expected recruitment then modulate this with a
    ‘ randomly chosen variate from a log-normal
    ‘ distribution of environmental impacts.
Call CalculateRecruitmentFromEggProduction

    ‘ Distribute the resulting recruitments between the
    ‘ two sexes and among the different depths and regions,
    ‘ in accordance with the specified input schedules
    ‘ provided by the biologists
Call DistributeRecruitsOverDepthsAndRegions

    ‘ Calculate the levels of fishing mortality that
    ‘ will be imposed on the fish of each sex within each
    ‘ age class, as determined from the input controls,
    ‘ i.e. fishery regulations, specified for each
    ‘ depth zone and region for the computer trial.
    ‘ Use the Baranov catch equations to calculate the catch,
    ‘ then apply the minimum and maximum size limits to
    ‘ determine the catch that will be landed and that
    ‘ which will be discarded. Calculate the total catch
    ‘ for each fishing sector for the year and the number
    ‘ of fish that will survive fishing mortality, natural
    ‘ mortality and discard mortality.
Call CalculateCatchAndSurvivalFromFandM

‘ Increment the model’s time clock by 1 week
ModelTime = ModelTime + 1

    ‘ Age the fish by one week, moving them into the
    ‘ storage space assigned to the next year-class if
    ‘ 52 weeks have elapsed since the last spawning event
    ‘ for the depth zone and region. Only one such
    ‘ spawning event is allowed each year.
Call AgeTheFishBy1Week

    ‘ Calculate over all depth zones and regions
    ‘ the number of fish that will move from that area
    ‘ to each other depth zone and region. Then, move
    ‘ the fish! The two-stage process ensures that fish
    ‘ that migrate from one area to another are not moved
```

```
    ' a second time (with ultimate results determined
    ' by the sequence in with the depth zones and regions
    ' are processed). The proportions migrating between
    ' depth zones and regions are determined from
    ' movement schedules (for each week, sex, and age class)
    ' provided by the biologists.
Call MigrateFishAmongDepthsAndRegions

Loop Until ModelTime >= MaximumModelTime

    ' Store the results of this trial for display or further
    ' analysis
    Call SaveTheResultsOfThisTrial
End Sub
```

Within each region, the first discrete event of each biological year is spawning by mature fish. The model calculates the egg production contributed by the females within each depth zone and region by calculating the sum over all age classes (from 1 year old to the maximum age) of the product of the number of females, the proportion of females of that age that are mature, and an age-dependent index of egg production, *i.e.* a value that is proportional to the egg production of females of that age class. The proportion of females of each age that are mature is determined from a maturity table, derived either from the proportions of fish of each age within a sample from the fishery or from a logistic curve fitted to these data using logistic regression analyses. The age-dependent indices of egg production are determined from a fecundity index table, which has been derived from estimates of total fecundity (or spawning biomass). The model recognizes that the date of spawning may differ in the different regions and depth zones, and tracks the age from that birth date until the fish migrate into other depth zones or regions (see later, as the multiplicity of birth dates and lack of information on natal origin represent an inconsistency in logic that the biologists need to reconcile). Other issues that arise from this specification are questions as to whether the proportion mature at age or the index of fecundity at age differ between depth zones and/or regions. The specific source of the data from which each of these tables are derived requires to be identified by the biologists.

A Beverton and Holt stock-recruitment relationship is used to estimate the value of recruitment from the index of egg production. This raises a question as to whether the egg productions from all depth zones and regions should first be combined before calculating recruitment. Such an approach would be consistent with a single breeding population, and would simplify the calculations but might best be simulated using a common spawning time. An alternative approach might be to use a common stock-recruitment curve over all depths and regions, but to calculate the recruitment of each depth zone and region from the egg production index for that depth zone and region. Another approach might be to first combine the egg production indices from the different depth zones to create a total egg production for each region before calculating recruitment. What approach would the biologists like to adopt for each species? Note that, if egg production indices are to be combined, a common "currency" is required. As the available data are unlikely to provide sufficient information to allow estimation of the parameters of the stock-recruitment relationship, consideration will need to be given to how the parameters might be estimated. For this, the meta-analyses carried out by Ransom Myers might be used to obtain an estimate of the steepness of the stock-recruitment relationship for stocks of species with life-history characteristics similar to those of dhufish and snapper.

The estimate of recruitment that is calculated from the stock-recruitment relationship will next be modulated by multiplying by a log-normally distributed random variate, selected from a distribution with appropriate parameters. The estimates of variability that are introduced into the assessments of maximum constant yield by fisheries scientists in New Zealand might provide parameters that will generate appropriate variability for the dhufish and snapper stocks.

The final recruitment calculation distributes the recruits from each depth zone and region, from each region or from the combined stock for the three regions into each depth zone and region. For this, appropriate tables of the proportion of fish settling into each depth zone and region are provided. Jill has suggested values of recruitment for dhufish of 25% for depths less than 20 m, 25% for depths from 20 to 40 m, and the remaining 50% to the third depth zone containing depths of 40 m or greater. A single table is provided if a single value of recruitment is calculated for the combined stock over all regions and depth zones, three tables (one for each region) are provided if the recruitment from each region is calculated, and 3*D* tables are provided if the recruitment from each depth zone and region is calculated. As there is likely to be little information available regarding the distribution of recruits among depth zones and regions, several different scenarios represented by different sets of tables of proportions recruiting will need to be defined by the biologists, to explore the sensitivity of the model. The sex ratio of recruits is assumed to be 1:1.

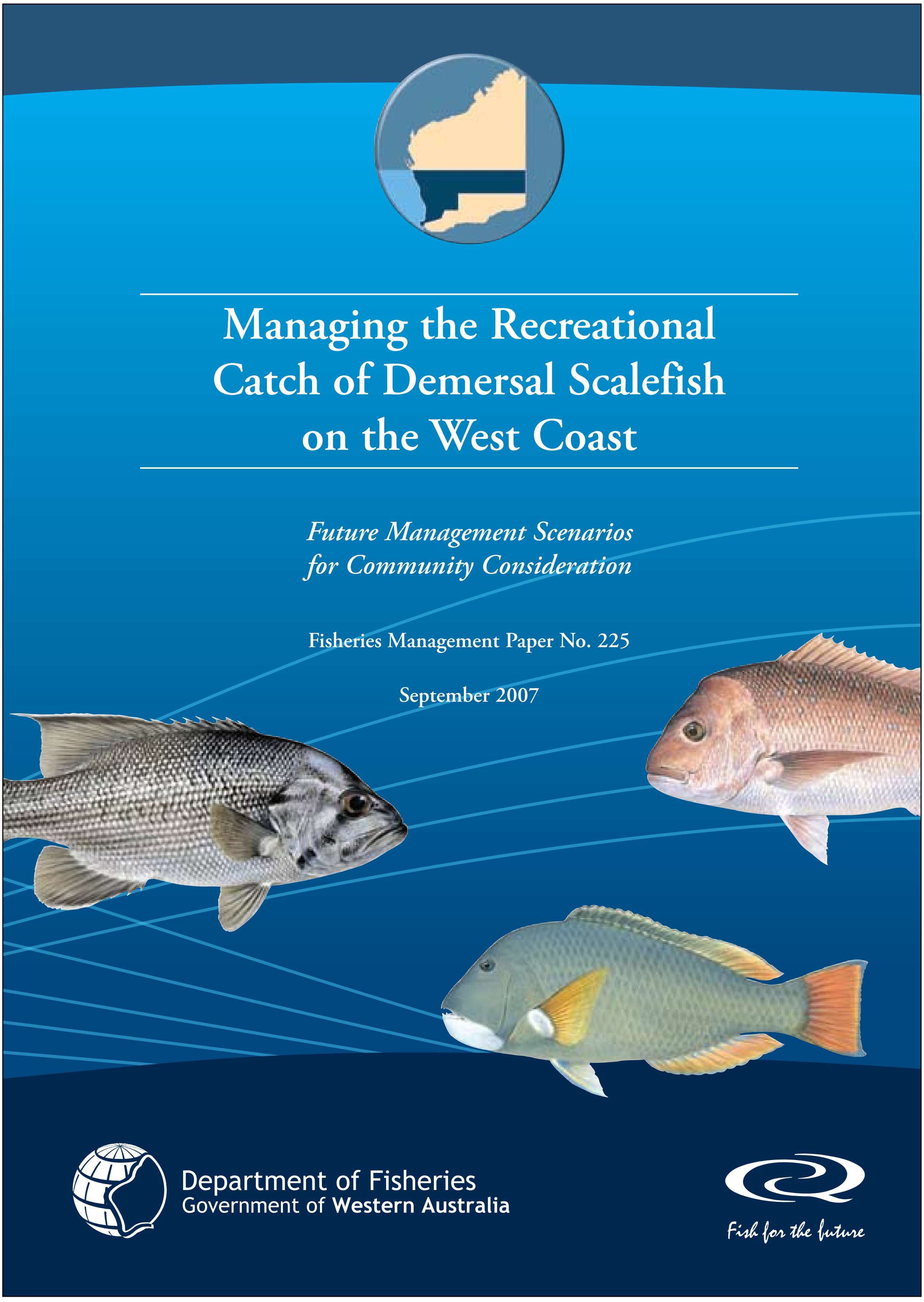
Constant levels of fishing mortality for fully-selected dhufish are assumed within each depth zone and region for each of the commercial and recreational fisheries, where these fishing mortalities are input by the biologists. Age-dependent fishing mortalities are calculated by multiplying the fishing mortality for fully-selected fish by the selectivity associated with the lengths of smaller fish. For dhufish, selectivity is assumed to be zero till age 3, then increases linearly with increasing length to attain a value of 1 at the length associated with age 6 then maintains this level of selectivity for larger fish. For snapper, fishing mortality is constant for both fishing and commercial sectors over all ages but increases to a new constant level for mature males and females for four weeks prior to or following the date of spawning. Different fishing mortalities are to be input by the biologists for each depth zone and region, for both the period of spawning aggregation and the remainder of the year. Selectivity of snapper is assumed to be 1 for all lengths. Fish that are smaller than the minimum legal length are assumed to be discarded. Discard mortality of dhufish is assumed to be constant, whereas, for snapper, it is constant for fish in depths less than 40 m, but increases to a new constant level for discarded fish from greater depths. Estimates of catchability will be input for each fishing sector to allow calculation of average catch per unit of effort.

Temporal and spatial closures of various spatial areas will be specified using weekly tables of the proportion of each depth zone within each region that are open (or closed) to fishing by either commercial or recreational fishers. These proportions will be multiplied by the age-dependent fishing mortality to reflect the reduced availability of the fish to that fishing sector. Temporal reductions in fishing mortality for each depth zone and region will be input using these same tables. Changes in minimum and maximum legal size (the default maximum size) will be input to the model and will be used to assess whether or not the fish that are caught must be discarded (and suffer incidental discard mortality). Catches that are taken by each fishing sector will be accumulated over each year. The model will allow input of TACs for each fishing sector and for each region, such that when the TAC is reached for the region, the fishery in that region is closed to the fishing sector (note – consideration needs to be given to transfer of fishing effort to other still-open regions).

Growth of fish is assumed to be sex dependent and is described by the von Bertalanffy growth equation. Separate growth equations are used to describe growth in each region. Since these are derived from the fish present within the region, and the natal origin of the individual fish is unknown, it is assumed that once fish migrate into a new region, they are assigned the age and birthdate of the fish within that region (a question for the biologists as to whether it might be better to assume a common birthdate, or to explore the sensitivity of the model to an assumption of a common birthdate rather than separate birthdates). Weight at length is calculated using a sex-dependent weight-length relationship. The average body weight of fish of each age is calculated as the body-weight at the mid-point of the week. Note that, since the parameters of growth and of the weight-length relationship do not change during the computer run, calculations of lengths and weights at age are performed at the start of the run and the results are stored, thus avoiding the need for recalculation at each time step of the simulation.

Migration of fish of each age and sex is calculated using tables of the proportions of fish that migrate to each depth zone and region from each other depth zone and region at each week. To simplify these calculations, common tables are assumed for both sexes and for most weeks. However, flexibility is maintained by allowing each table to be uniquely defined by the biologists.

Appendix 6. Fisheries Management Paper 225 – Managing the Recreational Catch of Demersal Scalefish on the West Coast



Managing the Recreational Catch of Demersal Scalefish on the West Coast

Future Management Scenarios for Community Consideration

Fisheries Management Paper No. 225

September 2007

Department of Fisheries
Government of Western Australia

Fish for the future

MANAGING THE RECREATIONAL CATCH
OF DEMERSAL SCALEFISH ON THE WEST COAST

Future Management Scenarios
for Community Consideration

FISHERIES MANAGEMENT PAPER NO. 225

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is available online **at www.fish.wa.gov.au**.

CONTENTS

EXECUTIVE SUMMARY 4

CONSULTATION PROCESS 6

MAKING A SUBMISSION 7

SECTION 1 SETTING THE SCENE 8

1.1 PROFILE OF THE WEST COAST DEMERSAL SCALEFISH FISHERY 8
1.1.1 Recreational fishing 9
1.1.2 Charter fishing 16
1.2 BIOLOGY AND ECOLOGY OF KEY DEMERSAL SPECIES 21
1.2.1 Dhufish 21
1.2.2 Pink snapper 22
1.2.3 Baldchin groper 22
1.3 RESEARCH AND MONITORING 23
1.3.1 How do we monitor stocks? 23
1.3.2 What is the current status of key demersal (bottom) species? 24

SECTION 2 KEY ISSUES FOR RECREATIONAL MANAGEMENT 27

2.1 HISTORY OF RECREATIONAL FISHERIES MANAGEMENT 27
2.2 HIGH MORTALITY OF RELEASED FISH 28
2.3 MULTI-SPECIES NATURE OF FISHERY 30
2.4 CONTINUAL IMPROVEMENT IN FISHING EFFICIENCY 30
2.5 INCREASING BOAT OWNERSHIP 31
2.6 NEED FOR DETAILED INFORMATION ON RECREATIONAL FISHING 33
2.7 SPATIAL SCALES FOR MANAGEMENT 33
2.8 LIMITATIONS OF CURRENT BAG, BOAT AND SIZE LIMITS 34

SECTION 3 HOW CAN WE CONTAIN RECREATIONAL CATCHES? 37

3.1 WHAT TOOLS CAN WE USE TO MANAGE RECREATIONAL CATCHES? 37
3.1.1 Registration system – an essential monitoring tool 37
3.1.2 Explicitly managing the catch through a form of tag system 39
3.1.3 Restricting effort through closed seasons 40
3.1.4 Restricting effort through closed areas 42
3.1.5 Restricting effort through temporary corridor closures 43
3.1.6 Wilderness fishing areas 44
3.2 STRATEGIES TO SUPPORT NEW MANAGEMENT 46
3.2.1 Compliance and education requirements 46
3.2.2 Research data requirements 46

REFERENCES 48

EXECUTIVE SUMMARY

The West Coast Bioregion is home to a variety of fish species that live on or near the bottom. These fish are termed " demersal" species and include dhufish, pink snapper, baldchin groper, breaksea cod, queen snapper (blue morwong) and red snapper. These species are under increasing fishing pressure and the future management of demersal scalefish on the West Coast is now at the "crossroads". Commercial and recreational fishing need urgent changes to management arrangements so that iconic species such as dhufish and pink snapper are available for future generations.

Significant over-fishing of dhufish and pink snapper stocks is occurring on the West Coast[1]. The number of older fish in the population has fallen and fishing now relies on a few dominant year classes (10 to 13 year-old fish). The decrease in older dhufish and pink snapper has been caused by high fishing pressure, combined with a number of years of poor recruitment, with few juvenile fish entering the fishery. Baldchin groper stocks at the Abrolhos Islands are also being overfished.

Recruitment for dhufish, pink snapper and baldchin groper depends on favourable environmental conditions. There can be a number of years between successful recruitment events. Successful recruitment for dhufish has happened only a few times over the past 20 years. Catches must therefore be controlled so breeding stocks are maintained and good recruitment occurs when conditions are again favourable. Current research indicates that fishing mortality needs to be reduced by about 50 per cent across the West Coast Bioregion.

The new management arrangements that are urgently required for the commercial and recreational fishing sectors need to reduce the current catch levels and maintain them at sustainable levels. Dhufish and pink snapper will be able to recover if the necessary management measures are put in place now to protect breeding stocks. Delaying management will only worsen the problem and future management will need to be more severe. It may also mean fish stocks collapse and the fishery being totally closed.

The Minister for Fisheries has announced significant changes to the management of commercial catches of demersal scalefish on the West Coast. The Metropolitan zone (from Lancelin 31°S to south of Mandurah 33°S) will be permanently closed to commercial fishing for demersal scalefish. This closure will involve the cessation of commercial fishing by line fishers and the demersal gillnet and longline (shark) fishery. The new managed commercial fishery, the West Coast Demersal Scalefish Fishery, will be a small viable line fishery targeting demersal scalefish across the Kalbarri, Mid-west and South-west zones[2].

Commercial fishing effort will be tightly regulated to constrain the commercial component of the catch to sustainable levels. Other commercial fishers not in the West Coast Demersal Scalefish Fishery will not be permitted to take demersal scalefish while undertaking other commercial fishing activities (e.g. fishing for rock lobster), even for personal consumption.

However, changes to commercial fishing alone will not be sufficient to ensure that the total catch is at sustainable levels. Recreational catches reductions are also required; however, minor changes to the current recreational controls, such as bag and size limits, will not be sufficient to achieve the necessary reductions. A new management approach is required.

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[1] Fisheries Research Report No. 163
[2] Fisheries Management Paper No. 224

This paper discusses the major issues around controlling the total recreational catch. It also considers some of the tools available to manage the catch to specific target levels. The sustainability of fish species must be a key driver. However, the impacts on the social amenity of recreational fishing must also be taken into account. Any particular tool, if used on its own and to its full extent, may be rather "blunt" in its application and its impacts unacceptable to large parts of the community. The most effective and acceptable management package will probably be a mix of tools, supported by effective education, compliance and monitoring programs.

The aim of this paper is to stimulate a broad level of community discussion and involvement in developing a way forward. The very nature of the changes required means that many individual fishers will have to modify their current fishing practices. By participating in this discussion, people have an opportunity to help develop new and innovative management options while minimising major impacts on the important social values of recreational fishing. Ultimately however, new measures must be introduced if we are to ensure the sustainability of key demersal fish species.

I encourage input from a wide range of interested individuals and organisations. This will be valuable in developing a dedicated and effective management package. With it we ensure future generations can continue to enjoy high quality recreational fishing experiences along the West Coast of Western Australia.

P J Millington
Chief Executive Officer

CONSULTATION PROCESS

An extensive consultation process will follow the release of this discussion paper and the research reports on the status of demersal fish stocks off the West Coast.

The aims of the consultation process will be threefold:

1. to promote community understanding of the sustainability issues;

2. to develop community understanding and discussion of the various management tools available that can effectively contain recreational catches in the long term; and

3. to gain an understanding of community views on preferred management approaches.

During the public comment period, meetings will be held in key population centres. These meetings will provide people with an opportunity to receive a briefing on the research conducted to date and how the fishery may be managed in the long term. They will also provide an opportunity to provide feedback to the Department of Fisheries on your thoughts and ideas. The details of these meetings will be publicised through print and electronic media.

Following the public comment period, a set of detailed proposals will be developed for the long-term management arrangements for the recreational fishery. These proposals will take into consideration the latest research findings and feedback from this discussion paper.

These proposals will be detailed in a Fisheries Management Paper that will be released for further public input on a new way forward for managing recreational fishing. It is anticipated this paper will be released early next year.

MAKING A SUBMISSION

The release of this discussion paper for public comment provides an opportunity for you to express an opinion on how recreational fishing for demersal species on the West Coast should be managed.

Points to consider for submissions:

To ensure your comments are as effective as possible, please:

- Clearly and briefly describe each separate subject you wish to address.
- Refer to the different sections in the discussion paper.
- Tell us whether you agree/disagree with the ideas.
- Suggest alternative ways to resolve the issues raised in this paper or identified by you.

Where to send your submission

The closing date for submissions is **16 November 2007**. Please send your submission along with your full name and address to:

Recreational Fishing Review
Department of Fisheries
Locked Bag 39
Cloisters Square Post Office
PERTH WA 6850

Alternatively you can enter your submission online by visiting the Department of Fisheries' website address at **www.fish.wa.gov.au**

SECTION 1 SETTING THE SCENE

1.1 PROFILE OF THE WEST COAST DEMERSAL SCALEFISH FISHERY

The West Coast Demersal Scalefish Fishery (WCDSF) extends from north of Kalbarri (27^o south latitude) to Black Point (115^o 30' east longitude), near Augusta (Figure 1). The West Coast Bioregion is home to a variety of fish species that live on or near the bottom. These fish are termed "demersal" species and include dhufish, pink snapper, baldchin groper, breaksea cod, queen snapper (blue morwong) and red snapper.

West Australian dhufish (*Glaucosoma hebraicum*)

Pink snapper (*Pagrus auratus*)

Baldchin groper (*Choerodon rubescens*)

Recreational fishing for demersal scalefish in the West Coast Bioregion is mainly from boats. Anglers typically use rods and reels or handlines, although a small proportion of demersal scalefish (less than 1 per cent) are taken by spear fishers, generally operating in water less than 20 metres deep.

The West Coast Demersal Scalefish Fishery comprises four zones:

Zone	**Typical catch**
Kalbarri	Pink snapper, sweetlip emperor
Mid-west	Dhufish, baldchin groper, pink snapper
Metropolitan	Dhufish, breaksea cod, pink snapper
South-west	Dhufish, pink snapper, breaksea cod, queen snapper, red snapper

Charter fishing is undertaken throughout the region, with 138 charter operators licensed to conduct tours in the West Coast Bioregion. These tours are conducted from key population centres, with the Abrolhos Islands being a focal area for tours in the Mid-west zone. Some charter activity targets pelagic (surface swimming) species such as mackerel but catch returns indicate the vast majority of charter fishing activity is focused on demersal species.

1.1.1 Recreational fishing

The first 12-month survey of recreational boat fishing in the West Coast Bioregion, including the Metropolitan area, was conducted during 1996/97[3]. This survey provided comprehensive data on the recreational boat-based catch for the West Coast Bioregion.

The 1996/97 survey indicated fishing effort is highest within a 30km radius of available launching points. The Metropolitan area has the greatest number of registered boats. This indicates a higher level of fishing pressure is being exerted on stocks within this area. The recreational catch of dhufish in the West Coast Bioregion was highest in the area between Lancelin and Port Gregory (north of Geraldton). The majority of the catch is taken over summer, autumn and spring. Most angling events for demersal scalefish are single-day trips where anglers launch in the early morning and retrieve their boats in the afternoon, often with the onset of the sea breeze.

A repeat of the creel survey was undertaken in 2005/06[4]. The 2005/06 creel survey results show distinct changes in both the level and distribution of recreational fishing effort. People are now travelling greater distances to fish over a far wider area (Figure 2). There are still peaks in fishing effort around key launching sites; however, there is now considerable fishing pressure being exerted out to the 200m isobath. This trend is due to the growth in ownership of larger, faster boats and people travelling greater distances to catch fish.

Fishing pressure is now being applied by recreational fishers over the full habitat range of key species such as dhufish, which primarily occur in water less than 100 m.

A comparison of the total estimated recreational boat-based line fishing effort and catch of dhufish and pink snapper shows significant changes between the two surveys (Table 1). A comparison of the distribution of dhufish and pink snapper catches between the 1996/97 and 2005/06 creel surveys is contained in Figures 3 and 4. The proportion of the total dhufish and

[3] Sumner and Williamson 1999
[4] Fisheries Research Report No. 163

pink snapper catch taken by recreational fishers in the West Coast Bioregion has also increased between 1996/97 and 2005/06 (Figures 5 and 6).

Table 1. Recreational oceanic boat-based catch and effort for dhufish and pink snapper in the West Coast Bioregion for 1996/97 and 2005/06 (excludes charter catches)

West Coast Bioregion				
Years	**Boat based fisher hours**	**Boat based fisher days***	**Dhufish catch (tonnes)**	**Pink snapper catch (tonnes)**
1996/97	1,348,000	269,600	125 (48 Metro)	25 (10 Metro)
2005/06	1,557,000	311,400	186 (58 Metro)	40 (13 Metro)

* Assumes a five-hour average boat-based fishing day

Summary – Recreational fishing

- Recreational catch and effort is increasing.
- The recreational catch of dhufish has increased from 125 tonnes in 1996/97 to 186 tonnes in 2005/06.
- Recreational boat-based line fishing effort has increased from 269,600 days* in 1996/97 to 311,400 days* in 2005/06.

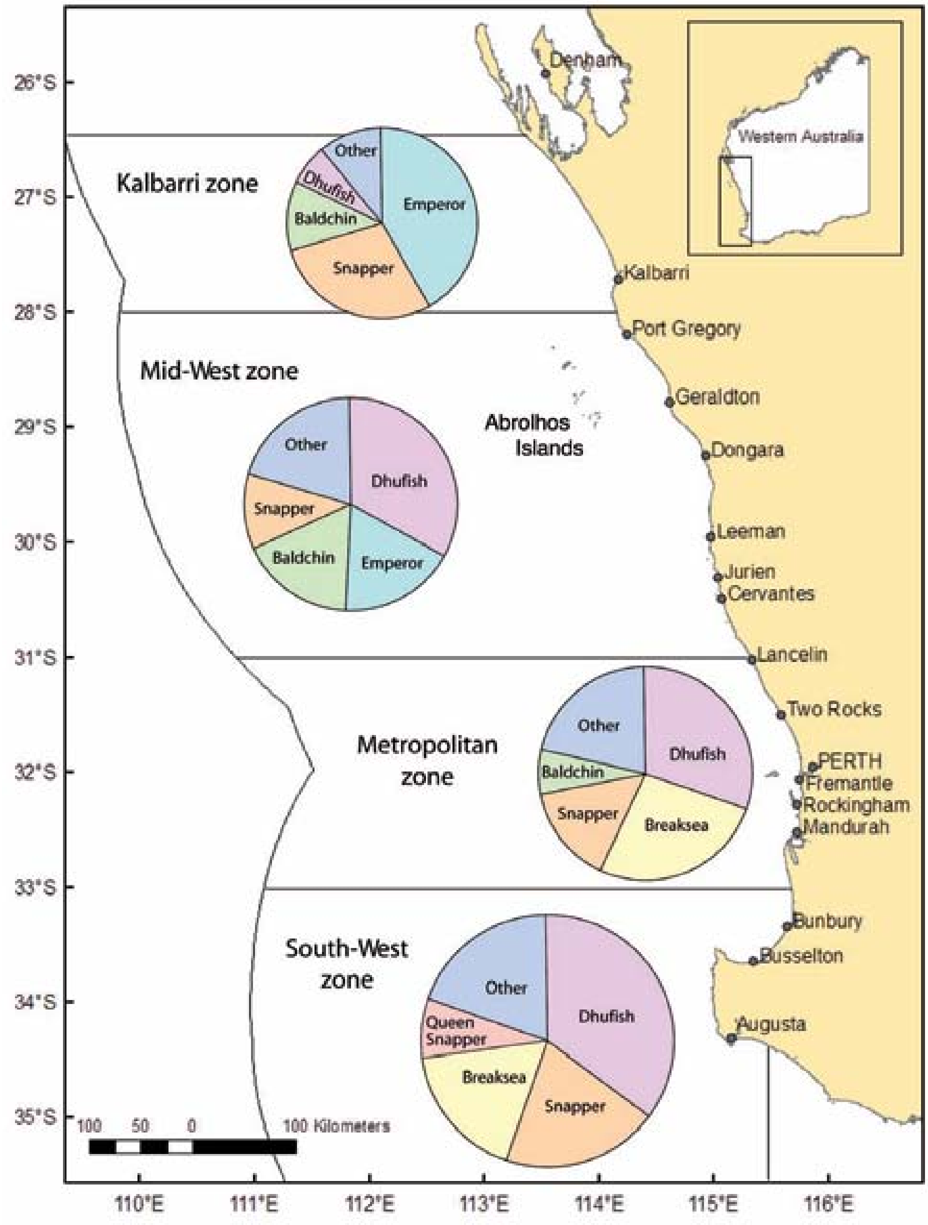

Figure 1. The West Coast Bioregion showing relative composition of key demersal scalefish taken by recreational fishers – 2005/06

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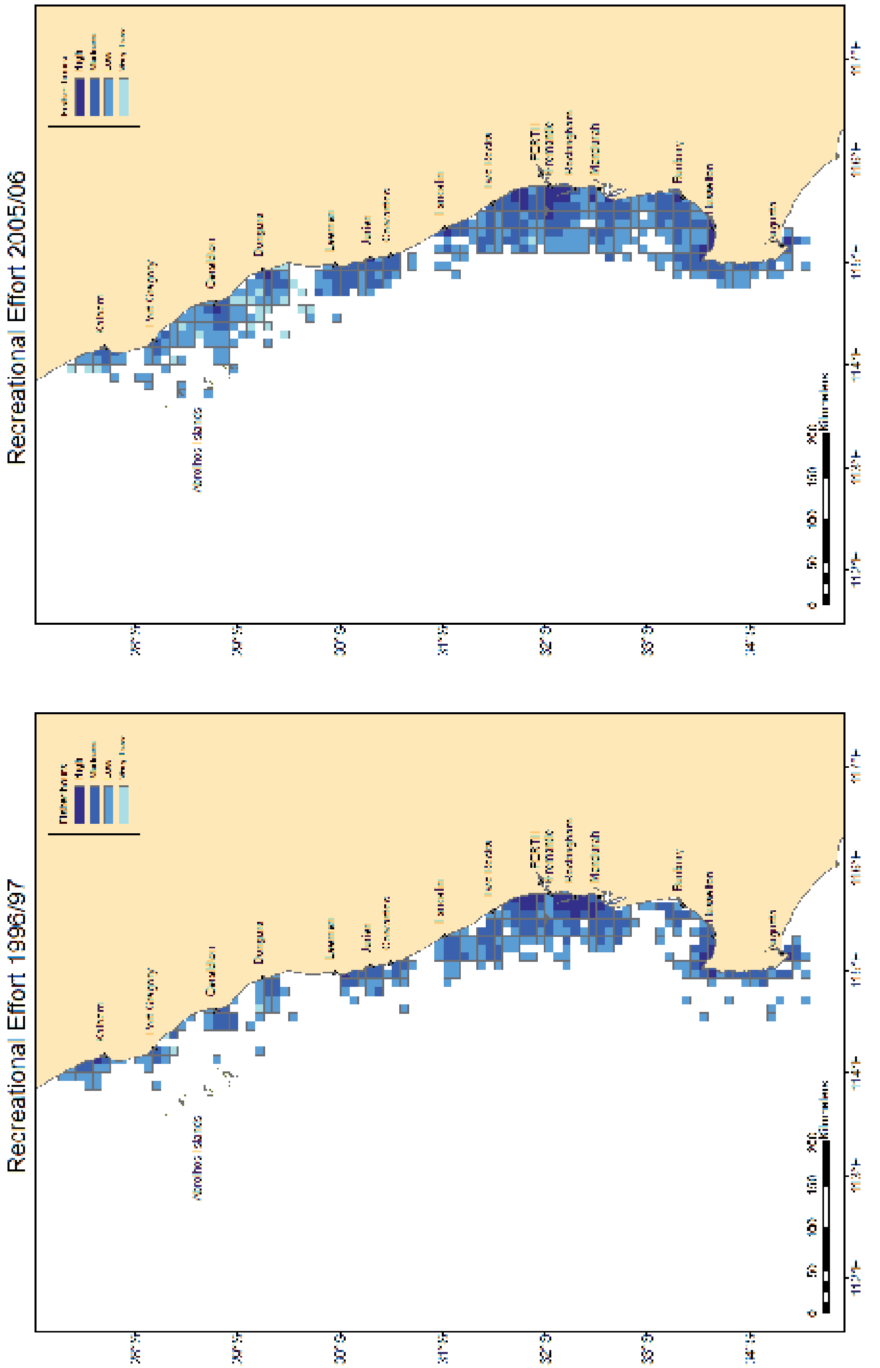

Figure 2. Estimated boat-based recreational line fishing effort using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06

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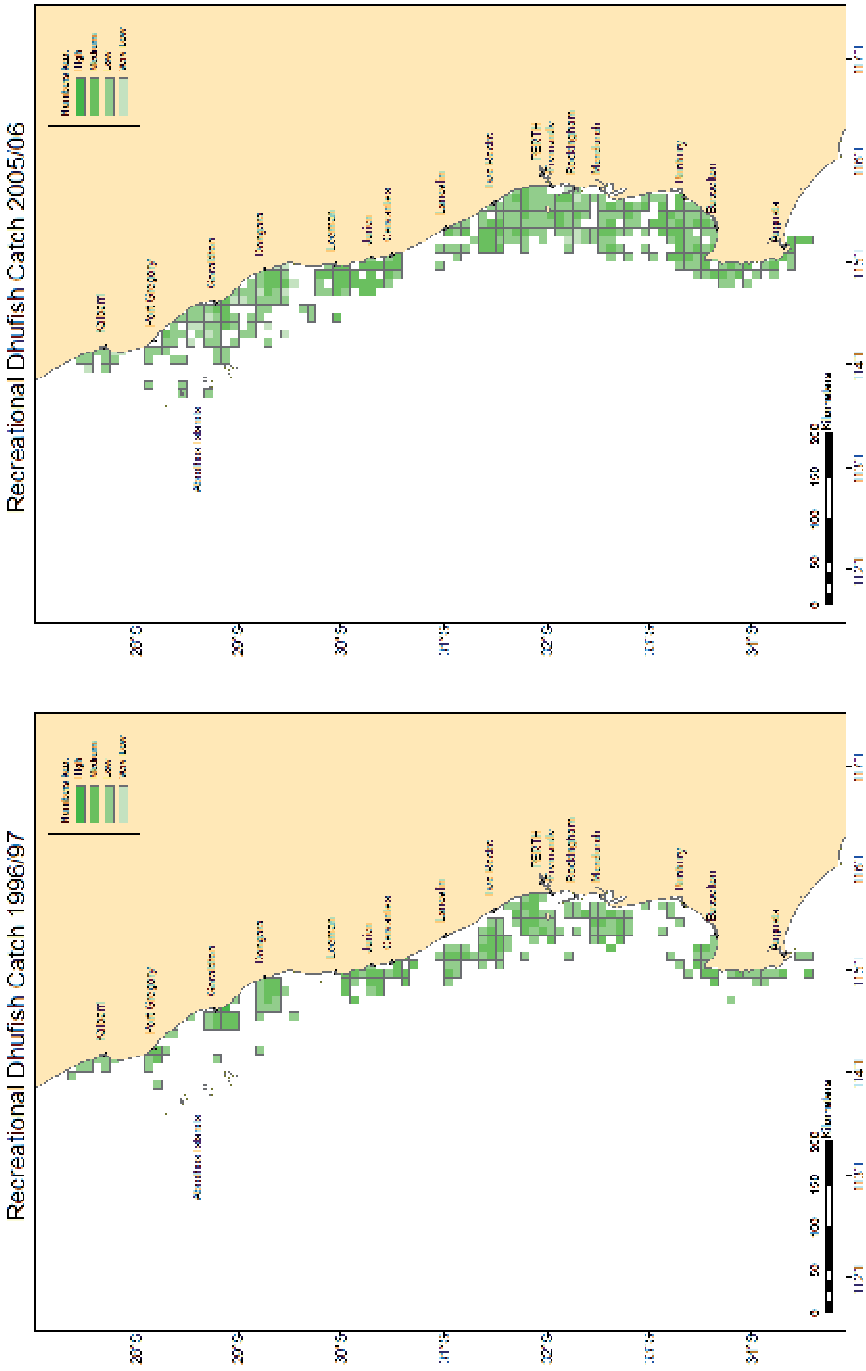

Figure 3. Estimated boat-based recreational dhufish catch using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06

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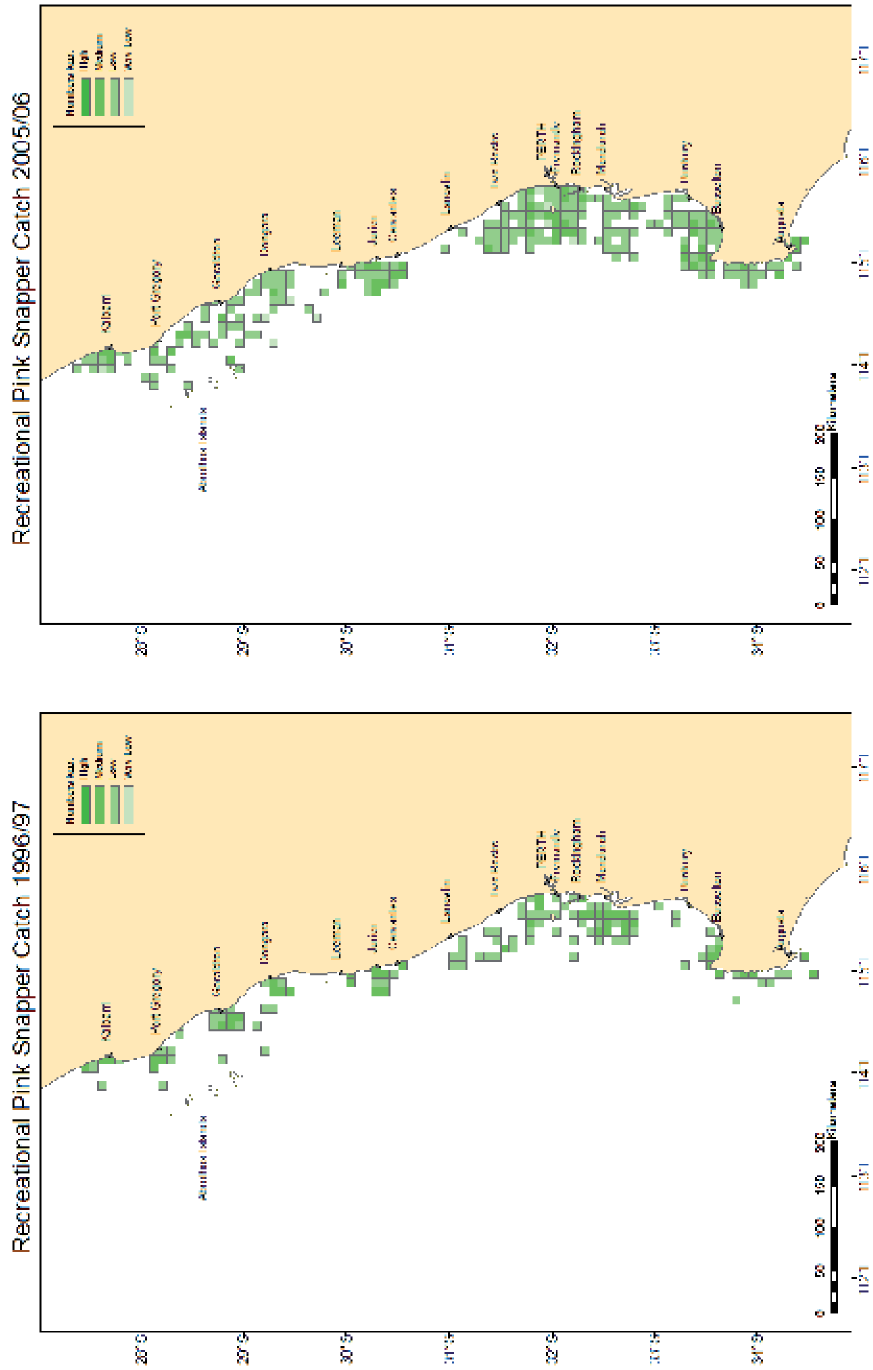

Figure 4. Estimated boat-based recreational pink snapper catch using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06

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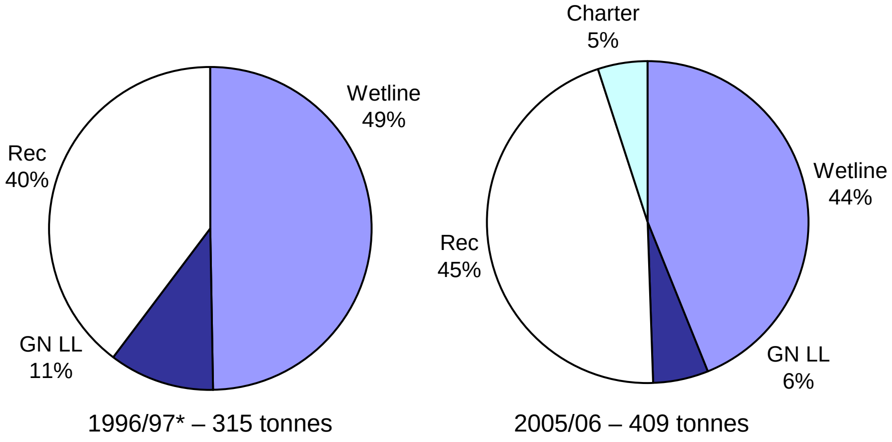

Figure 5. Proportional Dhufish catch by sector in the West Coast Bioregion in 1996/97 and 2005/06

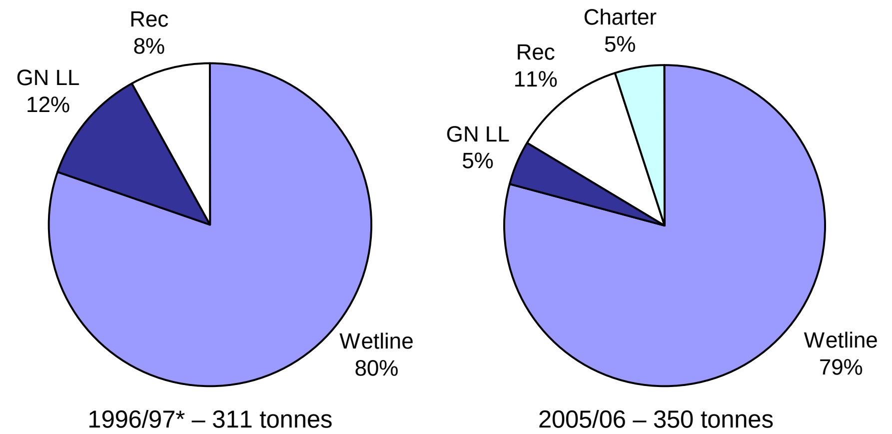

Figure 6. Proportional Pink snapper catch by sector in the West Coast Bioregion in 1996/97 and 2005/06

*** Charter catch not available - logbooks introduced in 2001**
 # GN LL – denotes Demersal Gill Net and Long Line (Shark) Fishery

1.1.2 Charter fishing

The West Coast Bioregion has the highest number of licensed fishing tour (charter) operators in the State. At the end of June 2006, there were 138 fishing tour operators, plus 23 restricted fishing and/or eco-tour operators licensed in the region. In 2005/06, 39 per cent of these licences were inactive in the West Coast Bioregion (i.e. they did not undertake fishing tours during that year).

Since 2002/03 when logbooks became compulsory, there has been an overall contraction in the total effort and operational area of charter activity in the West Coast Bioregion (Figures 7 and 10). This could be due to a number of factors such as a rationalisation of the industry after a limited entry licensing framework was introduced in 2001, increasing operational costs and rising fuel prices, or growth in recreational boat ownership. Charter effort has been consistently high off Perth, Kalbarri and at the Abrolhos Islands.

The charter catch of dhufish has remained stable throughout the West Coast Bioregion, with the exception of the Metropolitan zone, which has dropped from 13.4 tonnes in 2002/03 to seven tonnes in 2005/06 (Figures 8 and 11). The charter catch for pink snapper in the West Coast has also remained stable, except for 2004/05 where the catch rose to 24.6 tonnes (Figures 9 and 12).

Summary – Charter fishing

- Between 2002/03 and 2005/06 fishing effort in the charter fishery has decreased and charter catches of dhufish and pink snapper have remained stable.
- In 2005/06 the charter sector took about 10 per cent of the total recreational catch of dhufish and about 30 per cent of the pink snapper catch.

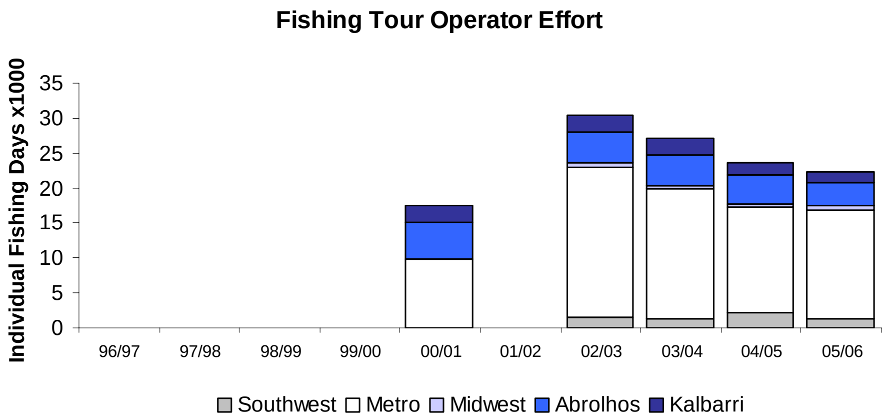

Figure 7. Tour Operator effort (individual fishing days) in the West Coast Bioregion. (Note: National recreational fishing survey data - 2000/01)

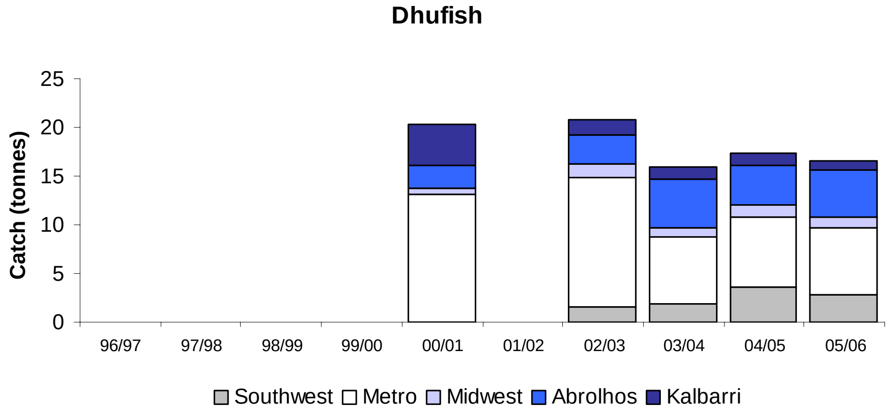

Figure 8. Dhufish catch (t) from Tour Operators in the West Coast Bioregion

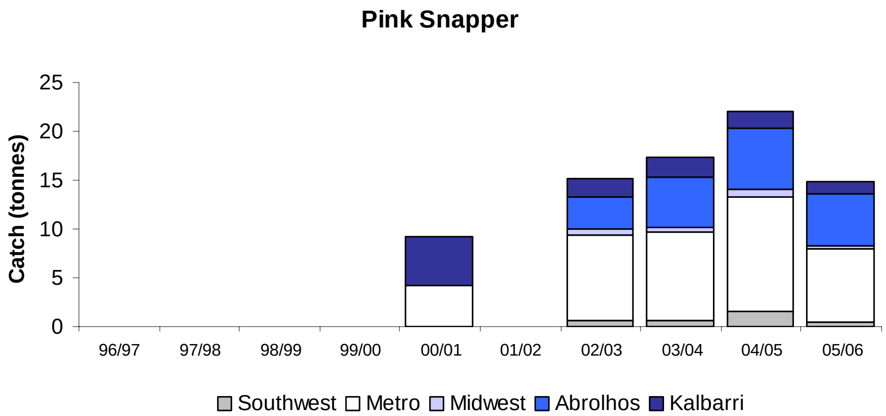

Figure 9. Pink snapper catch (t) from Tour Operators in the West Coast Bioregion

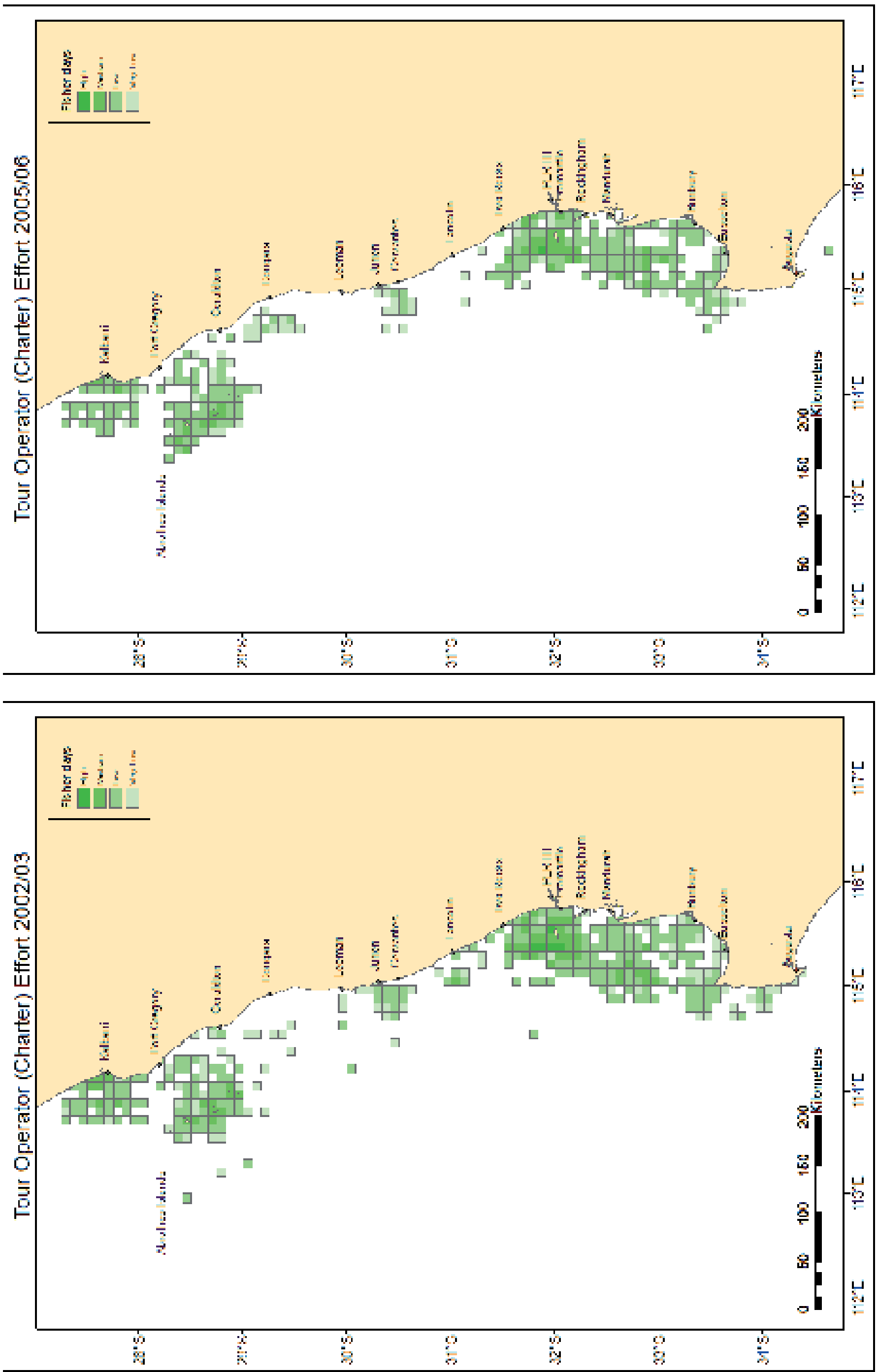

Figure 10. Tour operator (Charter) effort in the West Coast Bioregion for 2002/03 and 2005/06

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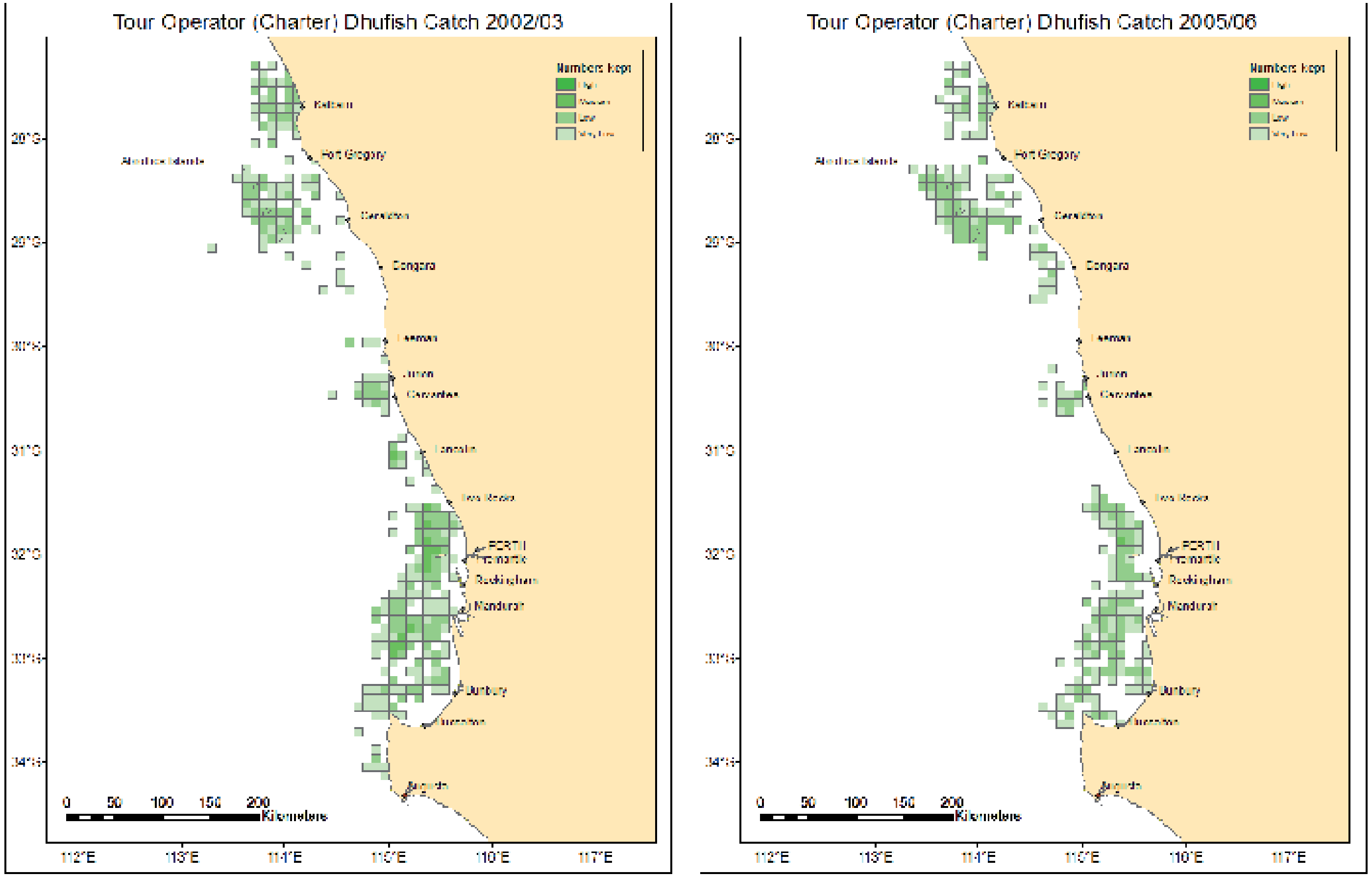

Figure 11. Tour operator (Charter) dhufish catch in the West Coast Bioregion for 2002/03 and 2005/06

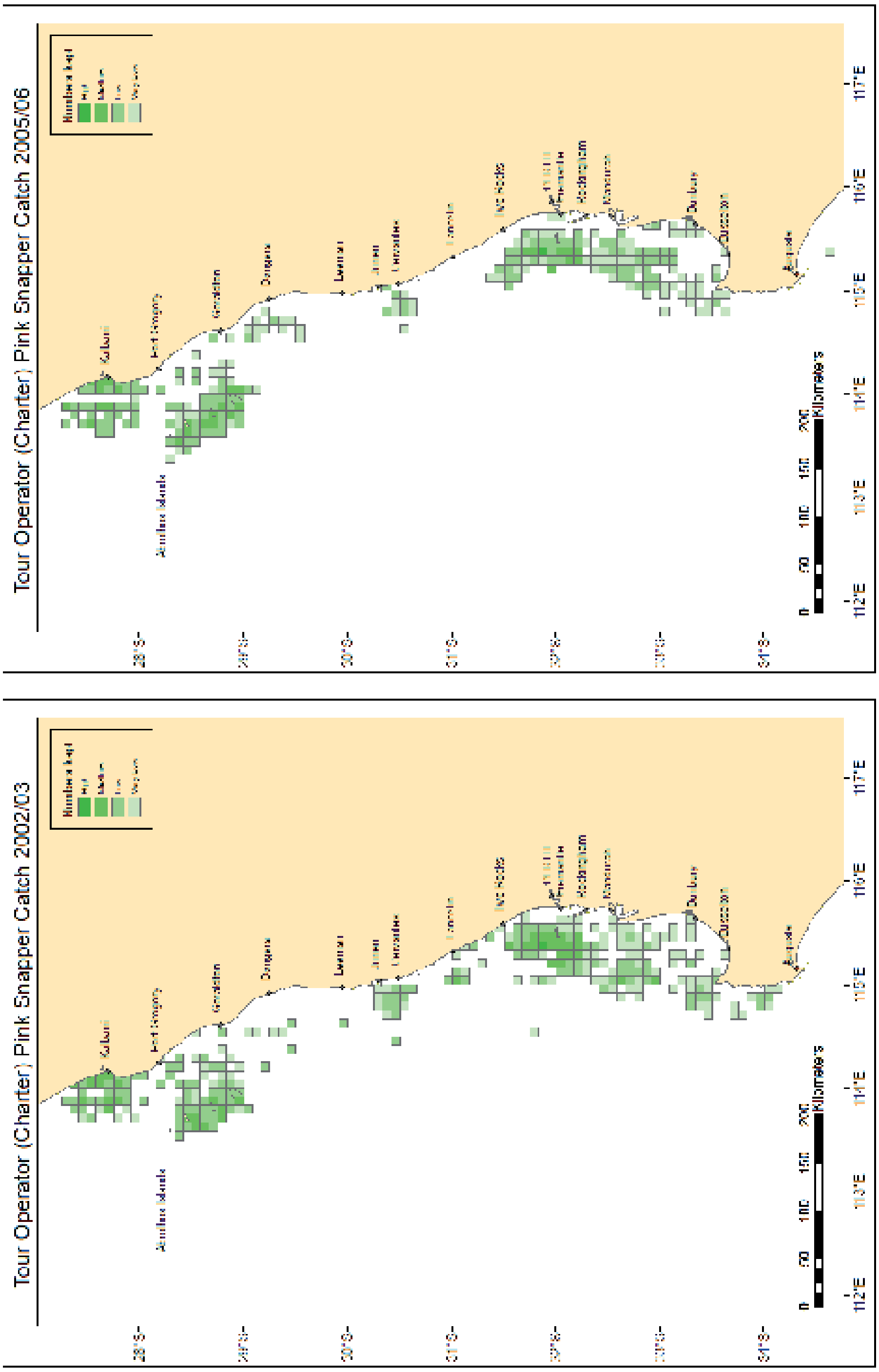

Figure 12. Tour operator (Charter) pink snapper catch in the West Coast Bioregion for 2002/03 and 2005/06

1.2 BIOLOGY AND ECOLOGY OF KEY DEMERSAL SPECIES

1.2.1 Dhufish

Dhufish are found only in Western Australian waters, generally between Shark Bay and the Recherche Archipelago. Like many demersal fish, dhufish are relatively slow-growing and long-lived with female dhufish growing slower than males. Dhufish reach the minimum legal size limit (500mm) at six to seven years of age and the maximum age for dhufish is at least 41 years[5].

Scientific and anecdotal information indicates that dhufish have a complex life history. Dhufish appear to exhibit social behaviour that implies some form of hierarchical social/mating during spawning. Unlike species such as baldchin groper, there is no evidence that dhufish change sex. Further investigation of their reproductive biology and behaviour is underway.

Dhufish spawn between November and April. The majority of spawning activity occurs between December and March. The size of the male gonads indicates that they probably undergo pair spawning. It is unlikely that dhufish form the large spawning aggregations that are common in species such as pink snapper. Anecdotally aggregations of 50 to 100 dhufish have been observed but this has yet to be substantiated.

Earlier research revealed that dhufish reach sexual maturity at lengths of between 300 and 350mm, by the end of their third year of life. Recent research has found that the smaller mature female dhufish do not effectively spawn throughout the entire spawning season. This relatively infrequent spawning, prior to the females reaching the current minimum size limit, results in a significantly lower level of egg production.

The older, larger fish in the population are very important to the reproductive dynamics of the population. Larger (older) females spawn more eggs, more frequently and over a longer period. They produce a substantially greater number of eggs per spawning season than younger, smaller fish.

It appears that large mature dhufish spawn during the summer breeding season. These larger dhufish may become more vulnerable to fishing during this time as they aggregate in groups.

Dhufish are susceptible to barotrauma (the effects of gas expansion in the body caused by rapid changes in water pressure) and release mortality is known to increase significantly with depth of capture (Section 2.2).

Summary – Dhufish biology

- The majority of dhufish spawn between December and March.
- It is unlikely that dhufish form large spawning aggregations.
- Dhufish are slow-growing and long-lived (maximum age 41 years).
- It takes six to seven years for dhufish to reach the current minimum size of 50cm.

[5] Hesp *et al* 2002

1.2.2 Pink snapper

Pink snapper are very widespread, occurring across the southern half of the continent, from Queensland on the east coast to Barrow Island on the northwest coast. They are similar to dhufish in that they are slow-growing and long-lived. On the West Coast pink snapper reach the minimum legal size limit of 410mm at approximately four years of age and the maximum age for pink snapper is at least 30 years.

The known major pink snapper spawning location in the West Coast Bioregion is in Cockburn Sound just south of Perth, which is also an important habitat for juvenile snapper (less than two years).

The legal minimum length is currently 410mm. This size was set following biological research on pink snapper stocks off Carnarvon. This research indicated that approximately 50 per cent of the stock was mature at 410mm. However, further biological studies have indicated that the size at maturity is approximately 100 to 200mm larger in the cooler waters of the lower West Coast[6]. That is, pink snapper in the lower West Coast appear to grow faster and mature at a larger size. Consideration may need to be given to reviewing the minimum size limit in the Mid-west zone and further south to provide adequate protection for breeding stocks.

It is likely that snapper in the Kalbarri zone are the same stock as those fish to the north in the Gascoyne Bioregion.

Summary – Pink snapper biology

- Pink snapper spawn between October and December.
- Pink snapper form large spawning aggregations (Cockburn Sound is the major known spawning area on the lower West Coast).
- Pink snapper are slow-growing and long-lived (maximum age at least 30 years).
- It takes four years for pink snapper to reach the current minimum size of 410mm.
- Pink snapper on the lower West Coast appear to grow faster and mature at a larger size than stocks of Carnarvon.

1.2.3 Baldchin groper

Baldchin groper are found only in Western Australian waters. They occur between Coral Bay and Geographe Bay. The Abrolhos Islands, situated off Geraldton in the Mid-west zone, form a focal point of abundance and major spawning ground for the baldchin population.

Baldchin groper are a slow-growing and long-lived species, reaching a maximum age of at least 20 years[7]. At the Abrolhos Islands they reach the current legal minimum length of 400mm at five to seven years[8]. Baldchin are also known to be protogynous hermaphrodites, meaning they change sex. They mature first as females when about 290mm in length and

[6] Fisheries Research Report No. 163
[7] Fairclough 2005
[8] Nardi *et al* 2007

three to four years and then change sex to become males when between 450mm and 550mm, at about 10 to 12 years.

Baldchin groper are known to spawn on a number of occasions over an extended spawning season from September to January at the Abrolhos Islands. Populations of baldchin are resident within reef systems with localised movements between shallow and deep water.

Baldchin groper are widely accepter as being extremely susceptible to barotrauma. Release mortality of fish is thought to be very high, even when captured in relatively shallow water.

Summary – Baldchin groper

- Endemic to WA with distribution centred around the Abrolhos Islands.
- Long-lived species that changes sex from female to male at 10 to 12 years.
- Thought to be extremely susceptible to barotrauma.

1.3 RESEARCH AND MONITORING

1.3.1 How do we monitor stocks?

When assessing the status of fish stocks, there are two basic types of analyses commonly undertaken:

- examination of historical catch, effort and catch rate data; and
- examination of age structure data and other biological variables.

The first type of analysis attempts to gain information on the status of stocks. It determines if a clear relationship exists between the catch rates (number of fish caught over a period of time) and changes in the relative abundance of the stocks. The second type of analysis examines what impact fishing may have had on the demography of the fished populations. It examines key features such as the age composition within the stock, size/age at maturity, plus their natural rates of recruitment and mortality.

When both types of data are available these can be combined to develop an integrated age-structured computer model that can provide estimates of the current biomass of a species relative to the biomass before any fishing started. This approach has been successfully applied to the stock assessments in WA fisheries including the Shark Bay Snapper fishery and the various stocks within the Pilbara Trap and Trawl and the Northern Demersal Scalefish fisheries.

In fisheries where the data are limited (e.g. catch per unit effort or age structure data are not all available), it is not possible to develop computer models that can estimate biomass. In such circumstances, a “weight-of-evidence” approach is considered to be best practice to assess the current status of a stock. This approach individually examines any quantitative measures that may be available, such as estimates of fishing mortality. It then considers these along with the biological characteristics of the species (including age, growth, habitat requirements and reproductive biology), environmental influences and operational characteristics of the fishery.

In the case of the West Coast Demersal Scalefish Fishery, information is largely limited to monthly catch and effort data provided by the various commercial fishing operations. These data were extensively analysed but due to changes in fleet dynamics and fishing efficiency a reliable index of stock abundance could not be generated.

Data on boat-based recreational fishing in the West Coast Bioregion is limited to two surveys undertaken in 1996/97 and 2005/06. Charter fishing catch and effort has been collected since 2001 and is based on logbook returns from operators licensed to carry out charter fishing in the West Coast Bioregion. Given the limitations of the available data, a "weight-of-evidence" approach has therefore been used to assess the status of key demersal species.

1.3.2 What is the current status of key demersal (bottom) species?

Recently concluded research studies show that dhufish and pink snapper are being overfished across almost all zones of the West Coast Bioregion[9]. The studies also show that baldchin groper at the Abrolhos Islands are being overfished. While the studies have focused on dhufish, pink snapper and baldchin groper, these species are considered "key indicator species" for monitoring the approximately 100 species of demersal fish taken in the West Coast bioregion.

The studies themselves presented some significant challenges and the data available are in some cases limited. However, the methodology and analyses have been reviewed by Associate Professor Malcolm Haddon (University of Tasmania), an internationally recognised expert in fish stock assessments. Professor Haddon has confirmed that they were 'best practice'.

The key piece of information available from the studies is 'F' – the fishing mortality. The value of F includes fish caught by commercial and recreational fishers. 'F' also includes the fish which are discarded as undersize and subsequently die from barotrauma-related injuries.

Where a species is being overfished, the age structure of the population is modified as fish are "cropped off" faster than they are produced. Older fish become uncommon in the population, which becomes dependent on fewer, younger age classes.

Fish age and size are not always well correlated. Large fish are not necessarily old fish, because for long-lived species such as dhufish and pink snapper, once individuals mature, growth rate slows markedly. So a fish of a given size can range from being relatively young to quite old. Age is determined by studying the otoliths (or ear bones) of the fish, which have marks in them similar to tree rings. Using this technique, the age structures of samples are determined. This analysis shows that the key indicator species on the West Coast are being overfished.

Another factor considered is the life history of the fish. Fast-growing, highly productive species can better withstand relatively heavy levels of fishing pressure. Slower-growing, less productive species (such as dhufish, pink snapper, baldchin groper and many other of the demersal species of the West Coast Bioregion) are much more vulnerable to overfishing and cannot withstand heavy fishing pressure.

[9] Fisheries Research Report No. 163

In some species, particularly dhufish, it appears that irregular recruitment adds a further complication. Successful recruitment "spikes" occur infrequently, generally as a result of favourable environmental conditions. This adds enormously to the vulnerability of these species. When a year class of fish resulting from a recruitment "spike" reaches legal size, catch rates and sizes of fish appear adequate, giving the appearance of a healthy stock. However, this can lead to false perceptions about the status of the stock.

Recent age structure information reveals that current dhufish catches are heavily reliant on 10 to 13-year-old fish. This population "spike" resulted from a period of successful recruitment between 1994 and 1997, when environmental conditions were thought to be favourable.

When fishing pressure is heavy, the "spike" (which contains the bulk of the breeding stock) can be rapidly fished down. Intensive fishing, coupled with unfavourable environmental conditions for recruitment can mean that the breeding stock is fished down to the point where it is unable to provide enough recruits to replenish the stock, even if the environmental conditions are favourable. The end-point of this scenario is a sudden stock collapse as the last of the "spike" is fish out.

The levels of fishing mortality of dhufish and pink snapper across all sections of the West Coast Bioregion (and for baldchin groper at the Abrolhos Islands) are above international benchmark standards. This indicates that these stocks are currently being overfished. Therefore under current levels of fishing pressure these stocks are probably being depleted to levels below those necessary to ensure their long-term sustainability. The current reliance of the dhufish catch on a single recruitment "spike" together with the significantly modified age structure for pink snapper (i.e. there are very few old fish remaining in the population) indicates that both of these stocks are particularly vulnerable.

Full details of the current stock assessment for West Coast demersal scalefish stocks are contained in *Fisheries Research Report No. 163 - Spatial Scales of Exploitation Among Populations of Demersal Finfish: Implications for management. Part 1: Stock status of the key indicator species for the demersal finfish fishery in the West Coast Bioregion (FRDC Project No. 2003/052)* (St John *et al*. 2007). A copy of the report can be found at www.fish.wa.gov.au.

While the currently available assessment only provides fishing mortality data, not the percentage of the spawning biomass, it appears highly likely that the stocks of these species are below (if not well below) a critical level. In order to maintain sufficient spawning biomass for the long-term sustainability of the key demersal fish stocks of the West Coast Bioregion, an immediate reduction in the level of fishing mortality on dhufish and pink snapper is necessary. Current research indicates a reduction of at least 50 per cent in fishing mortality is needed. This requires an immediate reduction in the overall catch (including discards) of these species.

The commercial and recreational fisheries currently involved in the exploitation of these resources are all capable of having considerable impacts on these stocks. There is an inherent high risk in leaving any of these sectors unmanaged. Consequently, comprehensive and effective management restrictions/limitations of all sectors will be required. The aim is to ensure sufficient breeding stock is maintained over periods of poor recruitment so that when breeding conditions are suitable, adequate breeding stock will be available to replenish the fishery.

Because of the inconsistent nature of dhufish recruitment, an initial reduction in effort/catch (including a complete closure) may not result in a recovery of this species in the short term. To achieve long-term sustainability it is essential that an adaptive management approach is taken. This involves monitoring the fishery to determine if the initial reduction in catch and/or effort is achieving the desired reduction in fishing mortality and if not, implementing further changes.

Summary – Stock status

- Dhufish and pink snapper are being overfished across large parts of the West Coast Bioregion.
- Baldchin groper are being overfished at the Abrolhos Islands.
- Recruitment for demersal species is variable.
- Current dhufish catches are heavily reliant on the last known recruitment "spike" which occurred between 1994 and 1997.
- There are very few older pink snapper and dhufish in the population.
- Current research indicates that fishing mortality for dhufish and pink snapper needs to be reduced by about 50 per cent across the West Coast Bioregion.

SECTION 2 KEY ISSUES FOR RECREATIONAL MANAGEMENT

2.1 HISTORY OF RECREATIONAL FISHERIES MANAGEMENT

Recreational fisheries in Western Australia have historically been managed on socially acceptable limits based upon a "fair day's catch" rather than on the status of fish stocks or their vulnerability to over-exploitation. This historical nature of "social" scalefish management is perhaps understandable, as Western Australia has a vast coastline that had been sparsely populated outside of Perth. The vastness of our coastline is however misleading, as WA's waters are nutrient-poor and comparatively unproductive for fish stocks.

The Recreational Fishing Advisory Committee (RFAC) developed the first management framework for recreational fisheries in Western Australia during a major two-year review between 1989 and 1991. The review took a State-wide approach as the first step in bringing the complete recreational fishery under a management framework. It established community consensus on the need for control of recreational fishing and the major strategies that should be adopted.

The first detailed catch survey of recreational boat fishing in WA was undertaken in the West Coast Bioregion in 1996/97. These results showed for the first time that the combined individual catches of recreational fishers formed a significant part of the overall catch of certain species[10].

During the mid to late 1990s planning began to shift management to a bioregional approach. This approach is better linked to the distribution of fish stocks and fishing activity, and capable of developing better targeted and more flexible responses to significant management issues.

During this period, the fishing and aquatic tour (charter) industry, previously an "open access activity", came under licensing and management arrangements. This sector is commercial in the sense that it is a fee-for-service industry; however, as the activity provides a platform for recreational fishing it is managed as a component of the broader recreational fishing sector.

The adoption of separate recreational fishing management strategies for each of the four bioregions, the Pilbara/Kimberley, Gascoyne, West Coast and South Coast, also saw the replacement of the previous bag limit categories. The old categories - prize fish, reef fish, key angling and sport fish, table fish and bread and butter fish - were replaced with three new simplified categories (Category 1, 2 and 3 fish). The new three-tiered system was based on a risk assessment framework, which took into account the level of risk (to sustainability) for each species.

The planning process for the development of the West Coast recreational fisheries management strategy recognised the growth in recreational fishing as a major issue for future management[11]. As a consequence, a number of precautionary reductions were made to bag limits for many targeted recreational species.

Notably, key demersal species were identified as high-risk species and included in Category 1 with a combined bag limit of seven fish. The individual daily bag limits for a number of key species were also reduced, including dhufish (from four to two), pink snapper (from eight to

[10] Sumner and Williamson 1999
[11] Fisheries Management Paper No. 153

four) and baldchin groper (from eight to four). Many recreational fishers saw these reductions as a “halving” of the recreational catch share. In their eyes this was inequitable, as despite the commencement of the “wetline” review, no changes in commercial management had yet been implemented.

At the same time some recreational and commercial stakeholders, and fisheries scientists and managers became more concerned about escalating catches of key demersal species such as dhufish and pink snapper. The Department of Fisheries was successful in gaining funding from the Fisheries Research and Development Corporation for three research projects on dhufish in the West Coast Bioregion. These projects focused on stock assessment, release mortality and spawning behaviour.

In 2004, Recfishwest (the peak body advocating for the interests of recreational fishers) organised a dhufish workshop, bringing together fisheries scientists, managers, recreational and charter fishers and some commercial fishers to discuss known information. The workshop concluded that a new approach to the way dhufish (and other demersal scalefish stocks) are managed will be required in the near future to protect the species for future generations[12].

Another catch survey of boat-based recreational fishing on the West Coast was undertaken in 2005/06[13]. These results found that despite the bag limit reductions implemented at the beginning of 2003, the recreational catches of key demersal species had increased. Dhufish catches had risen from 125 to 186 tonnes, pink snapper from 25 to 40 tonnes and baldchin groper from 23 to 33 tonnes.

Summary - Milestones in management of demersal species

- The first major State-wide review of bag and size limits was undertaken from 1989 to 1991.
- The first creel survey for boat-based fishing in the West Coast Bioregion was undertaken in 1996/97.
- The charter fishery came under management in 2001.
- In 2003 new rules were implemented for the West Coast Bioregion, including a halving of bag limits for dhufish, pink snapper and baldchin groper.
- A dhufish workshop was held in 2004 to review known information.
- A second boat-based creel survey was undertaken in the West Coast Bioregion in 2005/06.
- 2007 saw the completion of dhufish and pink snapper stock assessment on the West Coast.

2.2 HIGH MORTALITY OF RELEASED FISH

Many demersal scalefish species are susceptible to barotrauma when taken from deep water. Barotrauma is the effects of gas expansion in the body caused by rapid changes in water pressure and is akin to “the bends” in divers. Release mortality for captured dhufish is thought to be one of the highest recorded for key demersal species on the West Coast. This reflects

[12] Pagano and Fuller 2006
[13] Fisheries Research Report No. 163

45m). This is an important issue as discard rates (unwanted fish returned to the water typically because they are undersize) of dhufish are high across all sectors (commercial – 21 per cent, charter – 40 per cent, recreational – 43.5 per cent). Fishing mortality is probably significantly higher than the recorded levels of catch retained by all sectors.

The effects of barotrauma were examined in caging experiments where captured fish were released into cages back to the depth in which they were taken[14]. The mortality of dhufish increased significantly with depth of capture (Figure 13).

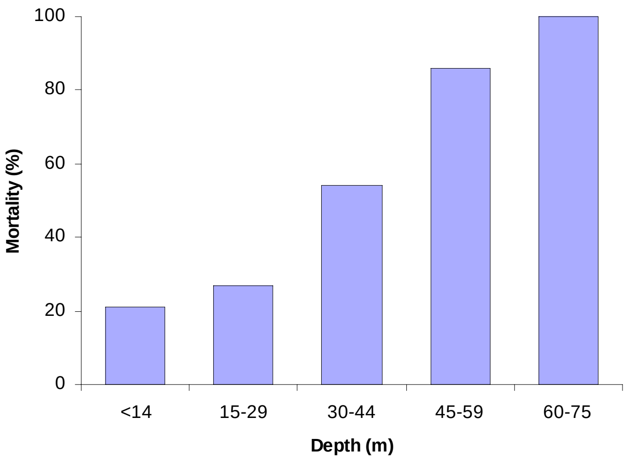

Figure 13. Mortality of WA dhufish caught at five depths

A Fisheries Research and Development Corporation funded tagging study on demersal scalefish on the West Coast is underway, coordinated by the Australian National Sportfishing Association (ANSAWA) and supported by Recfishwest. It has also been evaluating the level of release mortality of key species. A preliminary analysis of the recapture data from this study supports the increasing trends in mortality with depth for demersal scalefish. Very few dhufish recaptures are recorded from depths greater than 50m. This data will be fully analysed by the end of 2007.

While not immune to barotrauma issues, pink snapper are shown to be more robust than dhufish with some reported recaptures from over 100m in depth. Baldchin groper, on the other hand, are thought to seriously suffer from barotrauma issues with very few individuals surviving capture from comparatively shallow depths.

The biological attributes of demersal scalefish and their vulnerability to barotrauma may diminish the value of any measures that rely on the increased use of releasing captured fish (e.g. tags, changes to minimum legal sizes and changes to bag/boat limits). Therefore, the primary management goal for all sectors must be to develop arrangements that limit the total numbers of demersal scalefish that are captured.

[14] St John and Syers 2005

Summary – Mortality of released fish

- Mortality associated with barotrauma is a significant issue for many demersal species.

2.3 MULTI-SPECIES NATURE OF FISHERY

Recreational bottom fishing methods are relatively indiscriminate. The types of gear typically used to target key species such as dhufish and pink snapper are just as likely to catch individuals of a suite of other demersal fish species. The multi-species nature of the West Coast Demersal Scalefish Fishery, coupled with barotrauma issues in deep water, means it is not practical to manage a particular species in isolation.

Taking a multi-species approach to management is particularly important when considering management measures such as closed seasons, closed areas, tags or licences. The optimal time and place for a closure to protect spawning pink snapper may not match the biological requirements of dhufish or other demersal species.

Summary – Multi-species fishery

- The multi-species nature of the demersal scalefish fishery means that individual species cannot be managed in isolation from one another.

2.4 CONTINUAL IMPROVEMENT IN FISHING EFFICIENCY

Improved technology including Global Positioning Systems (GPS) and high-quality colour echo sounders have dramatically increased angler efficiency in the targeting of demersal species such as dhufish and pink snapper. Anglers are also taking advantage of improvements in angling gear, such as chemically sharpened hooks, low-stretch gelspun and braid lines and fishing rod and reel designs, which have improved catch efficiency, particularly in deep water.

The popularity of web-based fishing forums has also provided relatively inexperienced fishers with instant access to generations of local fishing knowledge. While this trend is good for anglers and their catch rates in the short term, the current exploitation rate is not sustainable in the long term.

Weather forecasting is also becoming more of an exact science with increased accuracy up to seven days in advance. This assists in the planning of fishing trips days well in advance, which may result in more effort days in the fishery.

Fishing technology in the future is likely to further improve the accuracy with which anglers can target fish. Ongoing mapping of benthic communities, improvements in digital imaging equipment, the adoption of underwater video technology and other advances will greatly increase the transparency of the ocean, and continue to make the finding of fish easier.

Summary – Improvements in fishing efficiency

- Technology improvements have resulted in significant increases in fishing efficiency that in turn is placing increasing pressure on fish stocks.

2.5 INCREASING BOAT OWNERSHIP

Boat registration information from the Department for Planning and Infrastructure shows a steady increase in the number of new boats registered across all size classes each year. In 2002 a total of 69,166 boats were registered in WA. By 2006 this total had grown to 81,417 with over 50 per cent of these based in the Metropolitan area alone. This represents an average growth in new boat registrations of approximately 2,450 per year, although it is recognised that not all boats are used for recreational fishing. Based on projected growth rates in 2010 there will be over 90,000 registered boats in WA (Figure 14).

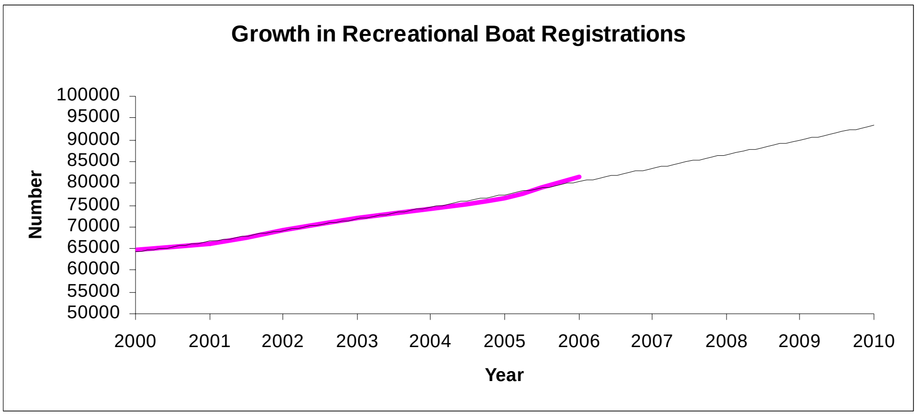

Figure 14. Historical and projected growth in boat ownership in Western Australia

In 2002, the distribution of registered boats in WA was closely correlated to the population distribution (Figure 15).

In recognition of the anticipated increases in recreational boating ownership in the Metropolitan area over the next 20 years, the Minister for Planning and Infrastructure has recently released the draft Perth Recreational Boating Facilities Study[15]. This study identified the need for a major increase in both boat ramps and boat pens along the 120km coastline between Two Rocks and Singleton to improve recreational access.

Summary – Boat ownership

- The combination of increased boat ownership and proposed additional launching facilities is likely to place further pressure on fish stocks.

[15] Department for Planning and Infrastructure 2007

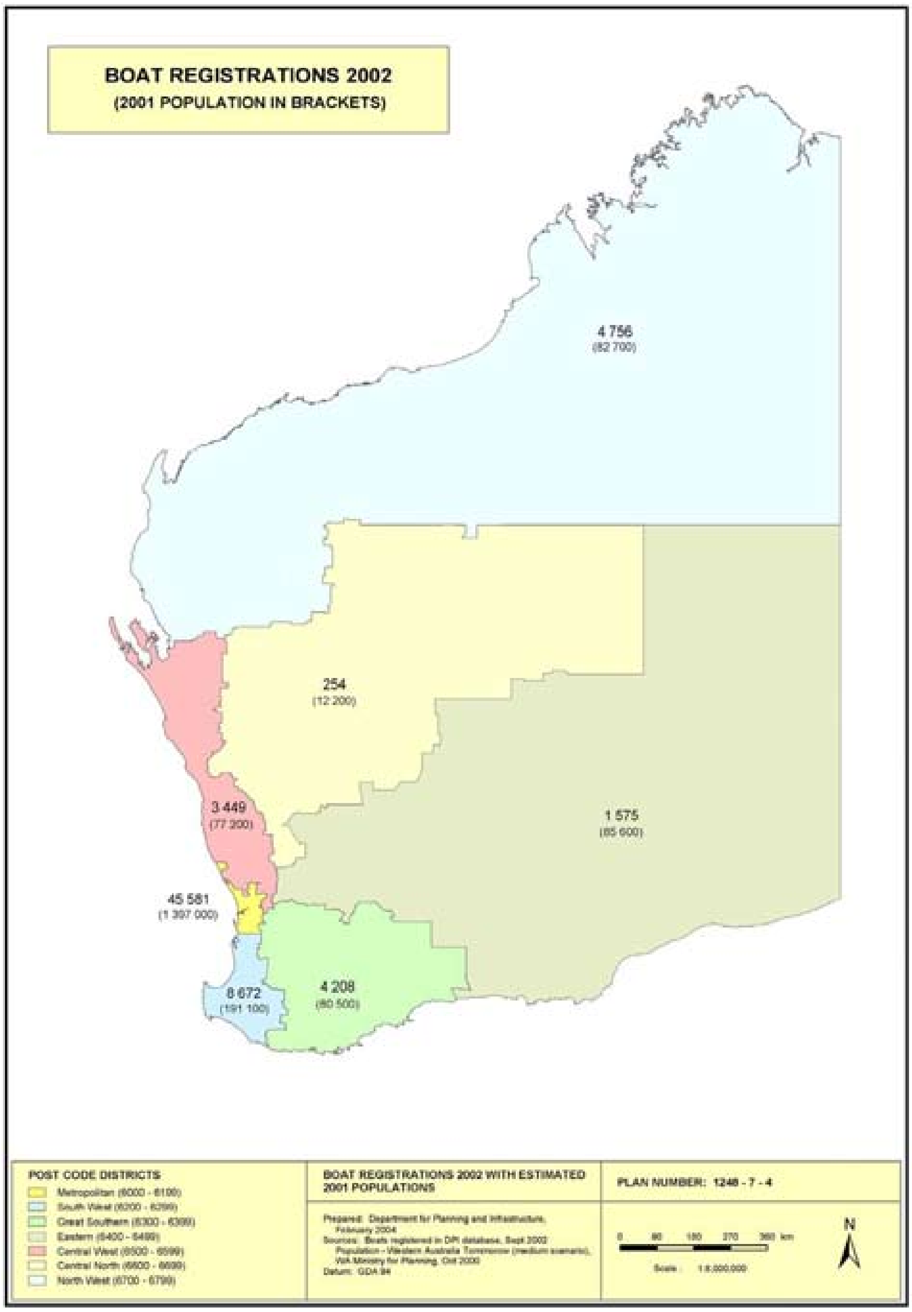

Figure 15. Distribution of boat ownership in Western Australia in 2002 (Department for Planning and Infrastructure 2004)

2.6 NEED FOR DETAILED INFORMATION ON RECREATIONAL FISHING

More detailed information on recreational fishing participation, effort and catches is essential to develop new management measures and to monitor and review their effectiveness. This type of information is essential for understanding what is being caught by the recreational sector, monitoring the status of stocks and assisting in resolution of fisheries management and resource sharing issues.

The existing information on recreational catches and fishing effort is provided by bioregional creel surveys. These surveys require considerable resources to undertake and only two surveys have been conducted on boat-based activity on the West Coast in 1996/97 and 2005/06. A gap of almost 10 years between surveys does not permit changes in recreational fishing to be monitored or assess the impact of recreational fishing on targeted fish stocks.

The Department of Fisheries has trialled the use of voluntary recreational angler logbooks on several occasions since the 1990s. These data provide important trend information on the relative levels of abundance of key indicator species over time. However, voluntary logbooks have a limited application in estimating total catch and effort or helping to assess the overall status of the stock.

Recreational fishing information needs to be collected on a continual basis to give better data on catches of the key indicator species such as dhufish and pink snapper. These data can either be collected via ongoing creel surveys or a survey of participants in the fishery that are determined through a registration system.

Summary – Need for more information on recreational fishing

- Recreational fishing information needs to be collected on a continual basis to give better data on catches of the key indicator species such as dhufish and pink snapper and evaluate the effectiveness of management.

2.7 SPATIAL SCALES FOR MANAGEMENT

Dhufish are found from Shark Bay to the Recherche Archipelago, with their primary range being from Kalbarri to Augusta. Pink snapper are more widespread and can be found across the entire southern half of the State.

Across the range of these species, stock abundance and biological attributes vary. Fishing pressure also varies with recreational creel surveys indicating that the highest level of recreational fishing pressure is currently in the Metropolitan zone (Lancelin to south of Mandurah). The West Coast Bioregion runs from Kalbarri to Augusta. This raises questions about the best spatial and biological scales of management – is it species, stock, bioregion or ecosystem – or a smaller scale? Recreational fishing currently is managed on a bioregional basis.

In recent times community expectations regarding appropriate scales of management have been expressed in the fishing media and on prominent recreational fishing websites, with some stakeholders calling for a separate zone of management in the Metropolitan area. This reflects the high levels of recreational participation and effort and the pressure these fish stocks are under in the Metropolitan zone.

Overfishing of pink snapper and dhufish stocks is occurring across the bioregion. Therefore management action will be needed to reduce catches across the entire West Coast Bioregion. This approach does not, however, preclude taking specific management action within a smaller zone of management if warranted.

Summary – Spatial scales for management

- While increased management of demersal scalefish stocks is required across the West Coast Bioregion, specific management action within a smaller zone of management may be warranted.

2.8 LIMITATIONS OF CURRENT BAG, BOAT AND SIZE LIMITS

The current recreational bag limits that apply on the West Coast were established following the bioregional review of recreational fishing in 2003. However, recent catch estimates from the 2005/06 creel survey highlight the limitations of bag limits as an effective management tool, particularly in the face of significant increases in fishing effort and technology gains in fishing efficiency. For example, during the 1996/97 creel survey, when a daily bag limit of four dhufish applied, an estimated 125 tonnes of dhufish were kept by recreational fishers. Despite a halving of the bag limit (from four to two) in 2003, the 2005/06 creel survey showed that total recreational catch had increased to 186 tonnes.

The bag limits for some individual species may have also reached a practical or socially acceptable limit. For example the current daily bag limit for blue groper and coral trout is one and the bag limit for dhufish is two.

Boat limits can potentially be used to reduce catches by restricting the total number of fish that can be taken by all anglers on a boat during a specific fishing trip. Based on the 2005/06 creel survey data, the total number of key demersal scalefish captured (dhufish, pink snapper, baldchin groper and breaksea cod combined) in the Metropolitan zone could, theoretically at least, be reduced by a varying amount by introducing a boat limit. For example, a boat limit of eight key demersal fish may have only reduced catches by 4 per cent; a boat limit of four may achieve a reduction of about 26 per cent and a limit of two by 55 per cent (Figure 16).

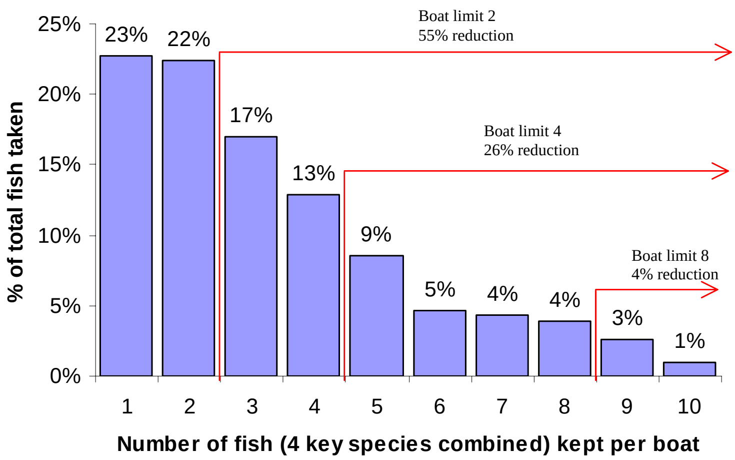

Figure 16. Percentage of the total number of key demersal scalefish (4 species) captured per boat in the Metropolitan zone on trips where one or more fish was kept (2005/06)

However changes in management arrangements can also lead to changes in fisher behaviour. Therefore the intended consequences of a new rule may not always achieve the intended result.

Setting minimum legal size limits is another tool that has been used to protect juvenile fish. Legal size limits are typically set above the size at maturity to enable fish to spawn at least once before legally being taken. Technically they are used as a part of a management package to help protect a sufficient proportion of the breeding stock from fishing. However, their effectiveness as a management tool is limited in fishing activities that have a high fishing mortality of discarded, undersize fish.

Maximum size or slot limits can be useful for protecting large breeding fish, or reducing the take of highly prized, and often rare, large specimens. Like minimum size limits, the effectiveness of maximum size limits or slot limits is species and habitat dependent and related to the survival of released fish and on the number of fish living long enough to reach that size.

Under the current WA fisheries law, minimum size limits apply equally to the recreational and commercial sectors. The development of the Integrated Fisheries Management initiative highlighted the fact there may be a case for different rules, including size limits, to apply in each sector[16].

[16] Fisheries Management Paper 165

Summary – Bag, boat and size limits

- Bag limits have a limited capacity to manage the recreational component of the catch where effort is unlimited.
- Boat limits can be used to manage recreational catches; however, their effectiveness over time can also be reduced when effort is unlimited.
- Size limits are used to protect a proportion of the breeding stock from fishing; however, their effectiveness as a management tool is limited in fishing activities that have a high fishing mortality of discarded, undersize fish.

SECTION 3 HOW CAN WE CONTAIN RECREATIONAL CATCHES?

3.1 WHAT TOOLS CAN WE USE TO MANAGE RECREATIONAL CATCHES?

The key to the long-term management of the recreational fishery is to find a combination of tools that can meet the sustainability requirements for the fishery while still allowing an enjoyable experience for the majority of fishers. Clearly the use of various tools will affect individual fishers in different ways and it is not always possible to meet everyone's expectations. What is the optimal mix of tools that meet the needs and expectations of most recreational fishers while maintaining a sustainable fishery?

The key requirements of a new management approach must therefore be threefold:

1. to be able to contain total recreational catch within target levels needed for sustainability;

2. to be able to monitor recreational participation, effort and catch on an ongoing basis; and

3. to be able to provide a quality recreational fishing experience.

The new management arrangements will need to be supported by effective education, compliance, and monitoring programs.

The following section outlines some of the options that are available and how they could be used to manage the recreational catch within the fishery.

3.1.1 Registration system – an essential monitoring tool

A registration system involves establishing a record or "register" of all people who wish to participate in the fishery. A registration system can be used to effectively monitor recreational catch and effort and accurately assess how many people fish, how often they fish and where they fish. This type of information has previously been obtained through the two recreational creel surveys and smaller annual phone surveys.

While creel surveys can provide comprehensive information on recreational catch and effort, they have only been able to be undertaken twice on the West Coast to date (1996/97 and 2005/06) due to resourcing constraints. To effectively monitor catches, this information needs to be collected much more frequently, ideally on an annual basis.

The Department of Fisheries also undertakes an annual community survey that provides basic information on Statewide recreational fishing participation. In the absence of a specific list or "database" of recreational fishers, this method relies on a relatively small number of random telephone interviews, and often results in highly variable estimates of participation.

A registration system is seen as an essential component of any future management strategy to provide more accurate, timely and cost-effective information on recreational participation and effort. A registration system not only provides accurate information on how many potential participants there are in the fishery, but also provides a ready made "database" to effectively target recreational fishers during telephone or mail surveys to obtain catch and effort information.

A registration system could also be structured to provide information on a smaller spatial scale. For example, when registering a person could be required to specify which areas they will fish in (e.g. Metropolitan area, Abrolhos Islands etc). Their responses to this question will provide extremely valuable information on the distribution of fishing effort and catch.

Undoubtedly, discussions of the merits of a registration system will lead to comparisons with previous debates over a general recreational angling licence. In the past the introduction of a general marine fishing licence has not been supported by some members of the recreational fishing community due to concerns over registration costs, the use of the revenue, as well as equity issues with pensioners, children and people who may only fish once or twice a year.

However, a registration system could be structured in such a way that only those people who wish to fish for vulnerable species of demersal scalefish or fish from a boat would be required to be registered. Registration fees could be developed in much the same way as the existing recreational fishing “licence” fee structure, with concessions for pensioners and children.

A registration system that offers variable time periods for participating in the fishery (e.g. days, weeks or all year) would provide important information on patterns of effort across the fishery (e.g. how many people fish year round, in summer months or only occasionally on annual holidays or ‘one-off’ fishing trips). Under such a system, registration fees could vary according to the time period required and people who only fish occasionally may not have to contribute as much towards management as someone who fishes all year round.

Government could potentially pick up the costs for management; however, there would be no incentive for people to register only for the time or area they intended to fish. This lack of incentive would reduce the capacity of a registration system to effectively evaluate recreational fishing participation on both a temporal (time) and spatial (area) scale.

To ensure all revenue generated through a registration system is used only in the management of recreational fishing, any funds raised would be paid into the Recreational Fishing Fund (RFF) established under Section 239 of the *Fish Resources Management Act 1994* (FRMA). All existing recreational licence fees[17] are already placed in the RFF and can be expended only on matters relating to recreational fishing, including management, research and compliance costs. Any unexpended balances at the end of a financial year are carried over to the following year.

Summary – Registration system

Positives

- Allows for the tracking of participation and effort over time.
- Provides a database to contact anglers to obtain more detailed and cost-effective information on effort and catch and timely management research information.
- Any funds raised through the registration system can be used for recreational fishing research, compliance and monitoring.

[17] A recreational licence is currently required to fish for rock lobster, abalone, marron, southwest freshwater angling and netting in Western Australia.

Negatives

- Requires all fishers to take out a registration before fishing.
- Cost for fishers to pay a registration fee, although this could be structured to allow for weekly, monthly or annual registration.
- Can require significant compliance resources to police.

3.1.2 Explicitly managing the catch through a form of tag system

A tag system is one measure that can be used to manage a recreational fishery to an explicit catch target. A tag system requires an angler to hold a tag if they intend to catch and retain a certain species. The tag must then be affixed to the fish immediately upon capture.

Under such a system, the number of tags issued is determined using the total target catch for the species and the average weight of fish caught. For example if the target catch for a species was 100 tonnes, and the average weight of fish taken by recreational anglers was 5kg, this would result in 20,000 tags being available for recreational fishers targeting that species each year.

In considering a tag system it is important to recognise that recreational fishing activity is targeted at a range of demersal species, including dhufish, pink snapper, breaksea cod, baldchin groper, queen snapper and red snapper. Given the multi-species nature of the fishery and mortality issues resulting from barotrauma for many of these species, a tag system may need to incorporate all demersal species. This may make it difficult to determine the number of tags that should be made available unless a more complicated system, such as using a range of species-specific tags, was implemented.

In the case of demersal scalefish, it is likely the demand for tags would far exceed the number of tags that would be made available (based on the sustainable catch). Therefore, to ensure the tags were distributed in an equitable manner, a lottery-type system may be needed where people have the opportunity to apply for tags, but only a certain number may be successful in the lottery and offered tags. If there is a high demand, the number of tags issued to each individual may need to be limited.

A tag system has been successfully used to manage the recreational and commercial take of pink snapper to an explicit level in Freycinet Estuary (Shark Bay) since 2004. In this fishery, recreational anglers may only apply for up to two tags per year. However, this fishery differs significantly compared to the West Coast Demersal Scalefish Fishery in that fishers can effectively target a single species in relatively shallow water where the survival rates of released fish is high.

Limiting individual fishers to a discrete number of fish could also encourage “high grading”. Some fishers may be tempted to discard a fish if a larger fish is subsequently captured, adding to the total fishing mortality.

If a tag system were established this may replace the need for a registration system, as only people with a tag would be allowed to retain the specific species that the tag system applied to.

Summary – Tag system

Positives

- Allows for the catch to be managed to an explicit level.
- Provides a database of all fishers who are entitled to retain specific species.
- The database could be used to contact anglers and provide the latest management and research information.
- Any funds raised through the lottery system could be used for recreational fishing research, compliance and monitoring.

Negatives

- A significant number of people may miss out on securing a tag.
- May lead to "high grading" where people only retain the largest fish. Barotrauma may increase the discard mortality.
- May impact on the quality of the recreational fishing experience.
- Cost associated with the production, distribution and purchase of the tags.
- Can require significant compliance resources to police.

3.1.3 Restricting effort through closed seasons

Closed seasons can be used to restrict effort by only allowing fishing for specified periods. Seasonal closures of various time scales have been successfully used to manage many fisheries in Western Australia. Short closures lasting several weeks are usually introduced for a specific purpose such as protecting spawning aggregations of pink snapper in Cockburn Sound and Shark Bay. Seasonal closures can also be used effectively to manage effort and catch; however they may need to extend over a significant proportion of the year depending upon the level of fishing effort and catch reduction required.

Examples of temporal closures designed to manage effort and/or catch include a four-and-a-half month closed season for the rock lobster fishery, a 23-day open season (or a 342-day closed season) for the recreational marron fishery and a six-day open season (or a 359-day closed season) for the West Coast recreational abalone fishery. In the case of marron and abalone, the combination of closures and bag limits has proven a successful management option in restricting catches to sustainable levels.

In examining the appropriateness of a seasonal closure it is first important to understand the current catch levels and management objectives.

For example, the management objective for the Metropolitan zone is based on research advice indicating that overall fishing mortality (catches) needs to be reduced by 50 per cent. In 2005/06 the total catch in the Metropolitan zone for dhufish was 107 tonnes and pink snapper 61 tonnes (Table 2).

Table 2. Commercial (wetline and gillnet/longline) and recreational (including charter) catches of dhufish and pink snapper in the Metropolitan zone in 2005/06.

Zone	Species	Commercial (t)	Recreational (t)	Total (t)
Metro	Dhufish	42	65	107
	Pink snapper	41	20	61

Using this example, catches of dhufish will need to be reduced by 53 tonnes (50 per cent) and pink snapper by 30 tonnes (50 per cent) in the Metropolitan zone.

The closure of the Metropolitan zone to commercial fishers for demersal scalefish has the potential to reduce the total pink snapper catch by 41 tonnes (approximately 67 per cent of the total catch). This measure alone exceeds the management requirement to reduce catches by 50 per cent (provided the recreational catch does not increase in the absence of commercial fishing).

The commercial closure will also deliver significant reductions in the dhufish catch of 42 tonnes (approximately 39 per cent of the total catch). However, an additional 11 per cent reduction in dhufish mortality is required. If this was to be achieved the fishery would need to be closed for a period over which approximately 11 per cent of the annual catch of dhufish is taken (Figure 17).

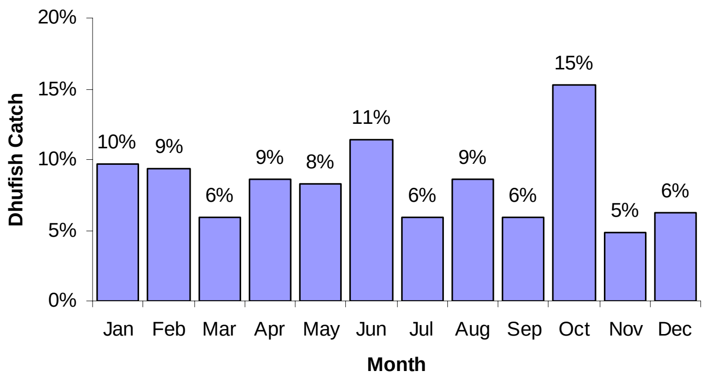

Figure 17. Estimated % of annual recreational dhufish catch taken each month in the Metropolitan zone – 2005/06

Given the multi-species nature of the fishery and mortality issues arising from barotrauma, any closure would have to cover all species likely to be caught while bottom fishing (e.g. dhufish, pink snapper, breaksea cod and baldchin groper).

The usefulness of a closed season could be undermined by a shift of effort to other areas or other times, although the extent to which this may happen is hard to predict. This highlights the need for an ongoing monitoring program to assess whether management changes are having the desired effect.

The appropriate timing of a temporal closure also needs to be considered in order to achieve the desired effect on catch. Factors such as peak spawning periods (e.g. December to March for dhufish and October to January for pink snapper) as well as seasonal variations in fishing activity need to be taken into account when considering the most appropriate timing for a temporal closure.

Summary – Closed seasons

Positives

- Can protect aggregations of fish.
- Can restrict catches by reducing effort.
- Allows for a quality fishing experience during the open season.
- Easy to administer.

Negatives

- Some fishers may fish harder prior to the start of the closed season and after the fishery re-opens. This may require the fishery to be closed for longer to deliver the required reductions in catches.
- Increasing fishing efficiencies and growing participation may require the seasonal closure to be extended to maintain catches at target levels.
- People may shift effort to open areas, requiring increased management of these areas.
- Long closures may impact on the recreational experience and industries reliant on this activity, e.g. charter, tackle, and tourism.
- Can require significant compliance resources to police.

3.1.4 Restricting effort through closed areas

Permanently closing certain areas to fishing can be used to either reduce catches (by limiting the areas that people can fish) or to protect breeding stocks. Permanent closures may be particularly beneficial for sedentary species that do not move outside the area. In such cases a closure may enable a proportion of the fish population to grow older and larger in the absence of fishing pressure. This could potentially benefit a fishery in two ways: firstly, the number of eggs a female is capable of producing each spawning event increases significantly with size, and secondly the older a fish becomes the more breeding seasons it would have contributed to, adding to the overall level of egg production across the fishery.

To be effective, spatial closures would need to be located in “meaningful” areas of a sufficient size that can provide protection for a significant proportion of the breeding stock. However, it is likely that an area that is important for one species will be different to that of other species.

There is no doubt that permanently closed areas can result in an increase in the local densities of some fish species, specifically those that are not highly migratory. However, many of the marine species subject to fishing are highly mobile either as adults, juveniles or both. This mobility greatly reduces the value of spatial controls for management at a stock level. It is therefore unclear whether establishing large permanent closures will help improve the quality of fishing for demersal species in the areas left open along the WA coast.

In order for a closure to be effective in reducing overall catch levels, it would need to be of significant size to provide adequate levels of protection for stocks. If the area to be closed is already a popular fishing area, the re-direction of fishing effort may reduce the local abundance of species in nearby areas. This may impact on fishing quality and negate the benefits obtained from the closure. In such circumstances, additional management controls in these adjacent areas are likely to be required.

It is therefore important to recognise that permanent closures must be considered as part of an overall management package, and cannot provide a solution on their own.

Summary – Closed areas

Positives

- May contribute to reducing catches if established on a large enough scale.
- Can provide increased protection for species if located in key areas such as spawning grounds.
- For some sedentary species, may create a reserve of mature fish that may contribute to the spawning biomass.

Negatives

- Depending on the location, permanent spatial closures have the potential to impact on some sections of the recreational fishing community more than others if the closure is established on local or favourite fishing locations.
- May not reduce catch if effort is transferred to other areas and could result in a detrimental impact on stocks in open areas that may require management.
- May lead to increased competition in open areas, which may reduce the quality of the fishing experience.
- Can require significant compliance resources to police.
- Assumes eggs generated in closed areas will contribute proportionally in subsequent recruitment.

3.1.5 Restricting effort through temporary corridor closures

A series of temporary "rotating" area or corridor closures is another tool available for recreational fishing management. Under this concept multiple areas of the fishery are closed to fishing for a specified time period (e.g. one to five years), after which they are re-opened and a series of new areas become closed to fishing.

Corridor closures have a capacity to reduce effort in much the same manner as permanent closures and are viewed by some fishers as being more equitable as they can "share" the impact of a closed area through the region.

However, given that successful recruitment may only occur once every several years for vulnerable demersal species such as dhufish, short-term corridor closures may prove of limited value in rebuilding and sustaining healthy stocks. If the area were reopened prior to it experiencing favourable conditions for successful recruitment, the previously protected breeding stock would become subject to "harvesting" and could quickly be lost to fishing mortality.

Summary – Corridor closures

Positives

- Temporary "rotating" closures may reduce catch to some extent.
- May provide additional protection for fish stocks over the specified time period.

Negatives

- Once an area is reopened the residual stock would become subject to "harvesting" and the benefits of having older and larger fish in the population could quickly be lost to fishing mortality.
- Given that successful recruitment may only occur once every several years for vulnerable demersal species such as dhufish, short-term corridor closures may prove of limited value.
- Effort may be transferred to other areas, reducing the capacity to manage total catch.
- Concentrating effort in open areas may reduce the quality of the fishing experience.
- Will require significant compliance resources to police.

3.1.6 Wilderness fishing areas

While not falling into the category of managing through effort reductions or explicit management of catch, there is the possibility of managing some areas as "very low take areas" or "Wilderness Fishing Areas". These areas are often remote and usually visited by people conducting extended trips.

If these areas have substantial fish stocks which contribute in a meaningful way to the overall spawning biomass, it may be possible to limit the take from these areas by allowing people to take only a small quantity of fish that must be consumed during the trip.

Within the West Coast Bioregion one area, which could be considered as a "no take-away area", is the Abrolhos Islands. Under this approach people could visit the Abrolhos Islands and the surrounding waters, fish and consume fish, but not take large quantities of fish back to the mainland. This approach could deliver substantial cuts in catches and prove to be more acceptable to the community than closed seasons or tags.

Summary – The impacts of Wilderness Fishing Areas

Positives

- Can restrict catches by allowing people to retain only what they can eat immediately.
- Can provide different types of quality fishing experiences within a region.
- Easy to administer.

Negatives

- May cause transfer of effort to other areas, which could result in a detrimental impact on stocks, requiring revised management.
- Can require significant compliance resources to police.

3.2 STRATEGIES TO SUPPORT NEW MANAGEMENT

The implementation of new management arrangements for recreational fishing for demersal scalefish will need to be supported by additional education and compliance resources.

3.2.1 Compliance and education requirements

The Department of Fisheries recently completed a State-wide compliance risk assessment for recreational fishing for marine scalefish from boats. Recreational boat fishing was rated as a high risk due to the increasing population, participation in recreational fishing and the concerns around the sustainability of demersal scalefish stocks. For compliance to be effective, the Department should be achieving a contact rate appropriate for the management measures introduced for the fishery. To achieve this, an increase in the order of 15 additional Fisheries and Marine Officers will be required; however, this may vary depending whether compliance is primarily focused at the point of landing such as checking registrations, or at sea such as policing closure boundaries.

The proposed changes to the management arrangements for demersal scalefish stocks across the State are also likely to require an increase in resources to provide community education. There will be a need to develop and implement community education and interpretation programs to minimise the impact of recreational take, promote and establish conservation and environmental values in recreational fishers and provide information and advice to assist with compliance with recreational rules.

The Department is currently seeking additional resources to fund compliance and education programs associated with the management of demersal fish stocks on the West Coast.

3.2.2 Research data requirements

The ability to evaluate whether the management package is having its desired effect and to monitor stock recovery and its status in the longer term must be a fundamental part of the management strategy. To achieve the required levels of evaluation and monitoring, there is a need to collect ongoing research data on recreational catches and obtain the necessary biological information to undertake meaningful stock assessments.

Given the significance of this fishery to recreational and commercial fishers alike, and the vulnerable nature of these species, it is imperative that ongoing research is undertaken to monitor the stock status of key indicator species (dhufish and pink snapper) and assess the effectiveness of management changes.

At a minimum, this research should include an ongoing fish frame-sampling program (to continue to monitor age structure of dhufish and pink snapper populations) and recreational catch surveys to improve our understanding of the quantity of fish taken by recreational fishers and to assess the impacts of management changes. Additional studies on the reproductive processes, behaviour and environmental impacts on recruitment success would also be extremely valuable. Such studies would inform fisheries managers and the general community about the way in which particular management measures would affect reproductive and recruitment success.

Additional monitoring will be necessary to improve our scientific understanding of stock status to make clear decisions about the success of the package and ongoing recruitment levels and will require a significant level of additional funding. The ongoing monitoring of the key indicator species in the West Coast Bioregion is essential to evaluate whether the management package is achieving the required level of reductions in fishing mortality. It is likely to take three to five years before a robust evaluation could determine whether the package has been successful. During this period, with a suitably designed sampling program, it should also be possible to determine whether the lack of dhufish recruitment since the 1994 to 1997 "spike" has continued. If this turns out to be the case, an earlier reassessment of the package will be required.

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