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

Part 1: Stock status of the key indicator species for the demersal scalefish fishery in the West Coast Bioregion.
Final FRDC Report – Project 2003/052

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Summary

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Background

Overview of the Fishery

The West Coast Demersal Scalefish Fishery is a multi-species fishery that lands over 100 different species. The key indicator species are dhufish, pink snapper and baldchin groper. The West Coast Demersal Scalefish Fishery covers a number of multiple competing sectors including commercial fishing activities (the wetline fleet, the demersal gillnet and demersal longline ['shark'] fishery and ancillary activities by the rock lobster fishery), plus significant recreational fishing activities (boat-based angling and the charter boat fishery).

There has been growing concern from both the Department of Fisheries Western Australia and stakeholder groups in recent years about the sustainability of demersal scalefish stocks in the West Coast Bioregion. Given that these activities are principally located off the main residential areas of the West Coast Bioregion and there have been significant increases in both population size and fishing efficiency primarily through the use of Global Positioning Systems (GPS) and high quality colour echo sounders, increasing pressure is being placed on these demersal species.

Over the past decade the catches of the key indicator species by the commercial fishery have generally been increasing but the patterns for the species have been variable among years, especially amongst the different regions. The two years where recreational information is available (1996/97 and 2005/06) show an increase in catches.

Assessment methodology

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

1. examination of historical catch, effort and catch rate data, and
2. examination of age structure data and other biological variables.

The first type of analysis derives information on the status of stocks by determining if there is a relationship between catches and changes in the relative abundance (catch rates) of the stocks. The second type of analysis examines what impact fishing may have had on the biology and age structure of the fished populations, particularly in relation to key features such as the size/age at sexual maturity and their rates of recruitment and mortality.

When both types of data are available these can be used to develop an integrated model that can provide estimates of the current abundance of a species compared to that prior to any fishing. In fisheries where the data are limited (e.g. relevant effort, catch, catch rates or age structure data are not all available), it is not possible to develop models that can estimate stock abundance. In such circumstances, a ‘weight-of-evidence’ approach is now considered to be best practice to assess the status of a stock. This approach individually examines any quantitative measures that may be available (e.g. estimates of fishing mortality) and considers these holistically with objective interpretations of inherent vulnerability such as the species biological characteristics (e.g. natural productivity, habitat requirements etc.) in conjunction with any operational characteristics of the fishery plus the potential influences of environmental changes.

The historical data available for the West Coast Demersal Scalefish Fishery are largely limited to monthly catch and effort data provided by the various commercial fishing operations that had caught these species. These data were extensively analysed for changes in fishing efficiency and fleet dynamics however a reliable index of abundance could not be generated. A survey of boat-based recreational fishing in the West Coast Bioregion was undertaken in 1996/97, but until recently very little biological research work had been undertaken in this region on the key indicator species. With the increasing concerns regarding the status of dhufish stocks in the late 1990s and the early 2000s, a number of FRDC and other funded projects were undertaken to gather more data on this and other west coast demersal species (Hesp *et al*. 2002, Fairclough 2005, St John and Syers 2005, St John and Keay 2005, Nardi *et al*. 2006, Craine *et al*. 2007, Mackie *et al*. 2007 and St John *et al*. 2007). In addition, surveys of recreational fishing on these stocks were repeated using Department of Fisheries funds. Despite the substantial increase in information generated over the past 5 years, the limited availability of useful historical data meant it was not possible to develop stock assessment models that could reliably estimate biomass. The current assessment for the West Coast Demersal Scalefish Fishery, with the limited availability of useful historical data where it was not possible to develop stock assessment models that reliably estimate biomass, has been based on a ‘weight-of-evidence’ approach.

The assessments completed for each of the indicator species have been independently reviewed by Associate Professor Malcolm Haddon (University of Tasmania), an internationally recognized expert in fish stock assessments. Associate Professor Haddon is in high demand both in Australia and overseas for this type of review because of his extensive knowledge of fisheries science and his ability to provide independent, pragmatic reviews, particularly for fisheries that have limited data. Associate Professor Haddon confirmed that the methodology and analyses undertaken were ‘best practice’ given the dynamics of the species in question and the information available (see Appendix 1, the Executive Summary of Associate Professor Haddon’s report).

Evidence: Biology and stock assessment

Dhufish

Dhufish are endemic to the south-west coast of WA. They can be long-lived (>40years), and have low natural mortality which, combined with slow growth, results in relatively low productivity. They exhibit a complex reproductive strategy with a hierarchical social/mating system with the larger fish probably very important to the reproductive dynamics of the population. Replenishment of dhufish across their range occurs primarily through larval dispersal because the adult dhufish are sedentary with only a very low percentage of the population exhibiting significant movements along the coast (preliminary tagging studies), resulting in limited mixing between adult populations (otolith microchemistry studies).

Like many long-lived species, dhufish have variable levels of recruitment among years which leads to a population structure having strong and weak year classes. In the absence of fishing this can result in a relatively stable population size but when the levels of fishing mortality become high, variable recruitment can compound any declines that occur from exploitation and accelerate depletion. Furthermore, the recovery period for such stocks cannot usually be predicted with any level of confidence because it relies on the periodic, but irregular, occurrence of a good recruitment years which are not currently able to be predicted.

The current age structure of dhufish shows clear evidence of a high recruitment period that occurred during the four consecutive years from 1993 to 1997. This pulse has been maintaining the present high level of catches observed over the past few years which is dominated by fish aged 10 to 13 years. If no new recruitment pulse enters the fishery in the next year or so, once the current pulse is fished down it is likely that under present levels of fishing effort both the catch and catch rate will drop rapidly. If this occurs there will be a concomitant decline in the spawning biomass, which may affect the potential for strong recruitment in the future years.

Aside from the strong recruitment pulse, there is evidence of a substantial decline in the numbers of older fish during the past decade. The maximum observed age of dhufish has dropped 10 years from 41 to 31 years old, and the proportion of older dhufish (>13 year old) in the catch has decreased from 28% to 9%. This lack of older fish is indicative of recent depletion. It should be noted that while large fish are still being caught in the fishery, they are not necessarily old fish because length varies greatly with age. Length is not a good indicator of age, with a large dhufish of 900 mm total length possibly being anywhere from age 10 to more than 30 years due to growth slowing markedly after maturity and inherent variability in growth rate.

The decline in the adjusted wetline fishery catch rates in recent years is consistent with the estimates that current levels of fishing mortality are in excess of international benchmark standards (above the target, threshold or limit reference points depending upon the zone). In addition, recent experiments have revealed that post-release mortality for captured dhufish is the highest recorded for demersal species, reflecting their extreme susceptibility to barotrauma (21% mortality in waters 1-14 m, 86% mortality in water depths greater than 45 m).

The combination of high fishing mortality rates, sporadic recruitment, complex reproduction and susceptibility to barotrauma make dhufish especially vulnerable to the current level of fishing.

Pink snapper

Pink snapper have some of the same vulnerabilities to over-fishing as dhufish through their life history attributes, including a long life span (> 30 years), low rates of natural mortality, large size and age at maturity. In addition they form spawning aggregations that are predictable in time and space. While they can be successfully caught and released in shallow water, they suffer from the same level of post-release mortality from barotrauma as dhufish in deeper water (>40 m) so in those waters are not amenable to management measures that involve their capture and subsequent release (e.g. tags, changes to legal minimum sizes or bag limits).

A critical issue for pink snapper is that the large, predictable spawning aggregations targeted by fishers may result in continued high catch rates when the stock size is decreasing, which is known as hyperstability. Thus, the lack of change in their observed catch rates over recent years are affected by both hyperstability and the impacts of improved fishing technology.

Consequently commercial wetline catch rates adjusted for improved fishing technology show declines over recent years indicating declining abundance rather than a stable population size. In addition, the only known significant spawning site within the West Coast Bioregion (located in Cockburn Sound/Warnbro Sound) is a highly industrial area that is already subject to high and increasing human usage. The pink snapper stock in this area therefore requires special protection.

While pink snapper are a long-lived species, most of the catch in the West Coast Bioregion is now comprised of individuals less than 10 years of age (except for Cockburn Sound). The dominant age classes in the north of the bioregion ranged from 3 to 6 years, with every individual reaching legal size by seven years. The dominant age classes in the south ranged from 5 to 8 years, with every individual reaching legal size by five years.

The assessment of the status of the pink snapper stocks indicate that the levels of fishing mortality for this species are well above international benchmark standards (substantially above limit reference points) across all zones of the West Coast Bioregion.

Baldchin Groper

Baldchin groper are endemic to Western Australia and are found most abundant in the Abrolhos Island region. Biological information is available from Fairclough (2005) and Nardi *et al*. (2006). Assessment of the baldchin groper stocks on the West Coast revealed that the overall levels of fishing mortality were between target and threshold benchmarks. However, the level of fishing mortality at the Abrolhos Islands was above the threshold benchmark and combined with declining catch rates indicate that localised over-fishing is occurring.

Summary

The levels of exploitation on both 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 over-fished and therefore are being depleted to levels below those necessary to ensure their long-term sustainability. The current reliance of the dhufish catch on a single recruitment pulse together with the extremely truncated age distribution of pink snapper indicates that both these stocks are particularly vulnerable.

Decision rules for effort reduction

Decision rules are a management tool that is used to assist decision-making by setting out appropriate and pre-determined responses to a set or sets of circumstances. In fisheries, the use of decision rules converts information regarding the status of the stock (e.g. levels of fishing mortality) into appropriate adjustments to the level of effort and/or catch in a fishery (these are often termed harvest strategies). The actual level of reduction for each species in each location is determined from the ‘Risk’ within the confines of the decision rule (Table A).

Table A. Summary of species-specific decision rules based on fishing mortality and risk status derived from the biological characteristics of the species, for each location in the West Coast Bioregion.

Location	Decision rule Fishing effort	Risk status from biological features
Dhufish		
Midwest	reduced by 50%-100%	High
Metro	reduced by 10%-50%	High
South	to remain constant	Medium - High
Pink snapper		
Kalbarri	reduced by 50%-100%	Medium - Low
Midwest	reduced by 50%-100%	Medium - Low
Metro (Offshore)	reduced by 50%-100%	Medium - Low
Metro (Cockburn Sound)	reduced by 50%-100%	High
South	reduced by 50%-100%	Medium - Low
Baldchin groper		
Abrolhos	reduced by 10%-50%	Medium - High

Dhufish

The levels of fishing mortality for dhufish are above international benchmarks in all zones. Thus, fishing mortality for dhufish in the Metro zone is above the threshold and very close to the limit reference point, while in the Midwest zone levels of fishing mortality are above the limit reference point. In the south region the estimate of fishing mortality is between the threshold and the limit reference point. Integrating these results against the background of the biological attributes of dhufish (Table A), indicates that the overall level of fishing effort and catch of dhufish in the West Coast Bioregion needs to be reduced by at least 50%.

Pink snapper

The levels of fishing mortality for pink snapper are above international benchmark standards within all zones of the West Coast Bioregion. Integrating these results with the biological attributes of pink snapper (Table A), suggests there needs to be a high reduction in the overall level of fishing effort and catch in the West Coast Bioregion of at least 50%, but with a complete closure to all pink snapper fishing within Cockburn Sound given that this zone has the only known major spawning aggregation in the West Coast Bioregion.

Baldchin groper

The examination of the available data for baldchin groper reveals that levels of fishing mortality across the entire West Coast Bioregion are between target and threshold benchmarks. However, the level of fishing mortality for baldchin groper at the Abrolhos Islands is above the threshold benchmark indicating that localised overfishing is occurring and that management action for this species needs to be targeted at the scale of the Abrolhos Islands (Table A).

Conclusion and implications of the research

The assessments of the status of the key demersal finfish stocks in the West Coast Bioregion have undergone external peer review (Appendix 1) with the methods considered best practise for the circumstances and the conclusions considered valid and appropriate.

There remains, however, a level of uncertainty with regard to the precise status of the stocks of dhufish, pink snapper and baldchin groper due to the nature of the data and the resultant assessments. The data do not allow the proportion of the unfished or remaining breeding stock biomass to be determined. Without a precise stock biomass model, it is not possible to generate precise estimates of the level of reduction in catch/effort needed to achieve acceptable stock levels. Instead, the data and methods available here can only provide a guide to the level of effort and/or catch reductions that should achieve sufficient reductions in the level of fishing mortality to generate acceptable stock recoveries. Nonetheless the assessments clearly indicate that the level of fishing mortality for both species are well above international standards for sustainable exploitation and that significant overfishing is occurring.

To address the overfishing situation, significant and comprehensive management actions will be required. Major reductions in both fishing effort and catches of these resources will be needed to reduce the rates of fishing mortality to acceptable levels. Moreover, a holistic approach to the management of these resources will be needed to effectively deal with the implications of the complex biological attributes of these species and the multi-species and overlapping nature of the various commercial and recreational fisheries involved.

There is an inherent high risk in leaving any sector of commercial and recreational fisheries unmanaged because all fishing sectors currently involved in the exploitation of these resources are capable of exerting considerable impacts on these stocks. Consequently, comprehensive and effective management restrictions/limitations of all sectors are required to have a reasonable chance of initiating recovery. Levels of effort and catch across the entire fishery need to be reduced by at least 50%. Any reduction in effort and/or catch (including a complete closure), however, may not result in a recovery of this species in the short term due to the inconsistent nature of dhufish recruitment. Therefore, the most appropriate strategy is to adopt an adaptive approach to determine if the initial reduction in effort and/or catch is at least achieving the desired reduction in the level of fishing mortality.

Furthermore, the restrictions in effort and/or catch for each sector must encompass all key indicator species and consider their biological attributes. For example any measures that rely on the increased use of releasing captured fish (e.g. tags; changes to minimum legal sizes, changes to bag/boat limits) are inappropriate for dhufish and pink snapper in deeper waters. Hence, for dhufish the primary goal for all sectors must be limit the total numbers of dhufish and pink snapper that are captured.

As part of the management plan there is an obligation for on-going monitoring of the key indicator species in the West Coast Bioregion to evaluate whether the management package that is implemented is resulting in the required level of reductions in fishing mortality. Although it is likely to take three to five years before a robust evaluation could determine whether the package has been successful, a suitably designed sampling program during this period should be able to monitor dhufish recruitment. If the recent lack of dhufish recruitment continues, then an earlier reassessment of the package will be required. This additional monitoring will require a significant level of additional funding.

Key Words

West Australian dhufish *Glaucosoma hebraicum*, pink snapper *Pagrus auratus*, baldchin groper *Choerodon rubescens*, stock structure, otolith microchemistry, reproduction, spawning, age, growth, stock assessment, reference points, fisheries management.

Background

The Department of Fisheries, Western Australia has divided its vast marine jurisdiction into four bioregions. The West Coast Bioregion extends from Kalbarri (27°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 yet to be formalised West Coast Demersal Scalefish Fishery. The West Coast Demersal Scalefish Fishery will embrace the management of commercial, charter boat and recreational fishing of demersal scalefish.

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 and 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, dhufish (*Glaucosoma hebraicum*) pink snapper (*Pagrus auratus*) and baldchin groper (*Choerodon rubescens*) are under high recreational and commercial fishing pressure (Crowe *et al*. 1999, St John and 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 and 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 is little information on their biology south of Shark Bay. Preliminary data indicates that biological parameters, such as growth rates and reproductive cycle, vary strongly with latitude. The biology of baldchin groper has been published (Fairclough 2005 and 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. 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, reef fish catches 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 as many undersize fish do not survive after their release.

Need

To address the urgent issue of impending over-exploitation of reef-fish resources, the Western Australia Minister for Fisheries 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.

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 growth and reproduction (timing of /size at maturity).
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.

Structure of Report

This report is divided into two parts, the structure of which is shown in Figure A. Part 1 of the FRDC 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.

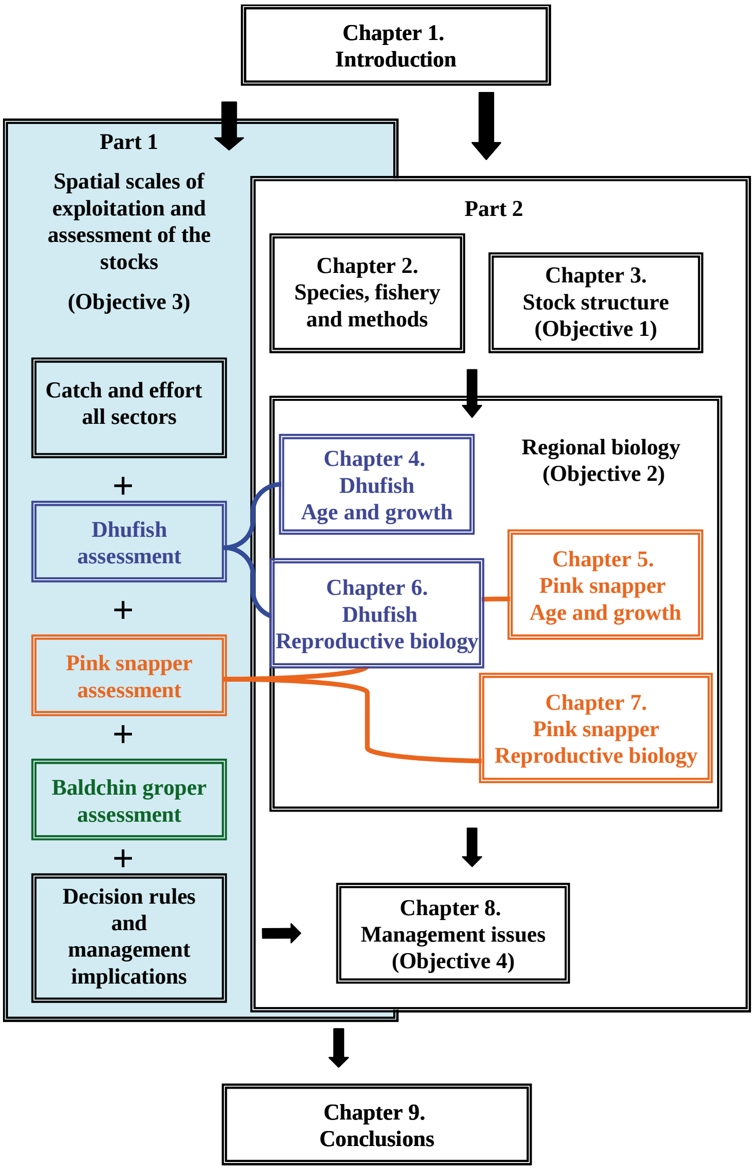

Figure A. Flow diagram of structure of FRDC reports Part 1 and 2.

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

Part 1: Stock status of the key indicator species for the demersal scalefish fishery in the West Coast Bioregion.

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Objective 3: To evaluate the spatial variation in the exploitation status of dhufish, pink snapper and baldchin groper captured in the West Coast Demersal Scalefish Fishery. Note: because the work undertaken in the FRDC Project will contribute to management of the entire West Coast Demersal Scalefish Fishery, the above objective was expanded to include a third indicator species, baldchin groper.

This work forms part of a study on the key indicator species for the West Coast Demersal Scalefish Fishery. This volume (Part 1) describes the stock status of pink snapper, dhufish and baldchin groper. Part 2 focused on only the former two species, describing their biology and stock structure in three regions within the West Coast Bioregion.

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1.0 Overview

The West Coast Demersal Scalefish Fishery is a multi-species fishery that lands over 100 different species. The key indicator species are dhufish, pink snapper and baldchin groper. The West Coast Demersal Scalefish Fishery covers a number of multiple competing sectors including commercial fishing activities (the wetline fleet, the demersal gillnet and demersal longline ['shark'] fishery and ancillary activities by the rock lobster fishery), plus significant recreational fishing activities (boat-based angling and the charter boat fishery).

There has been growing concern from both the Department of Fisheries Western Australia and stakeholder groups in recent years about the sustainability of demersal scalefish stocks in the West Coast Bioregion. Given that these activities are principally located off the main residential areas of the West Coast Bioregion and there have been significant increases in both population size and fishing efficiency primarily through the use of Global Positioning Systems (GPS) and high quality colour echo sounders, increasing pressure is being placed on these demersal species.

Over the past decade the catches of the key indicator species by the commercial fishery have generally been increasing but the patterns for the species have been variable among years, especially amongst the different regions. The catches of the three key species in the two years where both commercial and recreational data were available are:

	1996/97	2005/06
Dhufish commercial	191t	203t
Dhufish recreational	125t	206t
Pink snapper commercial	286t	293t
Pink snapper recreational	25t	57t
Baldchin groper commercial	37t	37t
Baldchin groper recreational	19t	37t

The 1996/97 recreational data is boat-based recreational catch only and does not include any catch taken from what were then unlicensed charter vessels. The 2005/06 recreational data is from both private boat-based recreational fishing and licensed charter operators. In the intervening years commercial catches were above 2005/06 levels (dhufish: 254t in 2002/03; pink snapper 356t in 2003/04; baldchin groper: 44t in 2002/03).

1.1 Assessment methodology

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

1. examination of historical catch, effort and catch rate data, and
2. examination of age structure data and other biological variables.

The first type of analysis derives information on the status of stocks by determining if there is a relationship between catches and changes in the relative abundance (catch rates) of the stocks. The second type of analysis examines what impact fishing may have had on the biology and age structure of the fished populations, particularly in relation to key features such as the size/age at sexual maturity and their rates of recruitment and mortality.

When both types of data are available these can be used to develop an integrated model that can provide estimates of the current abundance of a species compared to that prior to any fishing. In fisheries where the data are limited (e.g. relevant effort, catch, catch rates or age structure data are not all available), it is not possible to develop models that can estimate stock abundance. In such circumstances, a ‘weight-of-evidence’ approach is now considered to be best practice to assess the status of a stock. This approach individually examines any quantitative measures that may be available (e.g. estimates of fishing mortality) and considers these holistically with objective interpretations of inherent vulnerability such as the species biological characteristics (e.g. natural productivity, habitat requirements etc.) in conjunction with any operational characteristics of the fishery plus the potential influences of environmental changes.

The historical data available for the West Coast Demersal Scalefish Fishery are largely limited to monthly catch and effort data provided by the various commercial fishing operations that had caught these species. These data were extensively analysed for changes in fishing efficiency and fleet dynamics however a reliable index of abundance could not be generated. A survey of boat-based recreational fishing in the West Coast Bioregion was undertaken in 1996/97, but until recently very little biological research work had been undertaken in this region on the key indicator species. With the increasing concerns regarding the status of dhufish stocks in the late 1990s and the early 2000s, a number of FRDC and other funded projects were undertaken to gather more data on this and other west coast demersal species (Hesp *et al*. 2002, Fairclough 2005, St John and Syers 2005, St John and Keay 2005, Nardi *et al*. 2006, Craine *et al*. 2007, Mackie *et al*. 2007 and St John *et al*. 2007). In addition, surveys of recreational fishing on these stocks were repeated using Department of Fisheries funds. Despite the substantial increase in information generated over the past 5 years, the limited availability of useful historical data meant it was not possible to develop stock assessment models that could reliably estimate biomass. The current assessment for the West Coast Demersal Scalefish Fishery, with the limited availability of useful historical data where it was not possible to develop stock assessment models that reliably estimate biomass, has been based on a ‘weight-of-evidence’ approach.

The assessments completed for each of the indicator species have been independently reviewed by Associate Professor Malcolm Haddon (University of Tasmania), an internationally recognized expert in fish stock assessments. Associate Professor Haddon is in high demand both in Australia and overseas for this type of review because of his extensive knowledge of fisheries science and his ability to provide independent, pragmatic reviews, particularly for fisheries that have limited data. Associate Professor Haddon confirmed that the methodology and analyses undertaken were ‘best practice’ given the dynamics of the species in question and the information available (see Appendix 1, the Executive Summary of Associate Professor Haddon’s report).

1.2 Dhufish

Dhufish are endemic to the south-west coast of WA. They can be long-lived (>40years), and have low natural mortality which, combined with slow growth, results in relatively low productivity. They exhibit a complex reproductive strategy with a hierarchical social/mating system with the larger fish probably very important to the reproductive dynamics of the population. Replenishment of dhufish across their range occurs primarily through larval dispersal because the adult dhufish are sedentary with only a very low percentage of the population exhibiting significant movements along the coast (preliminary tagging studies), resulting in limited mixing between adult populations (otolith microchemistry studies).

Like many long-lived species, dhufish have variable levels of recruitment among years which leads to a population structure having strong and weak year classes. In the absence of fishing this can result in a relatively stable population size but when the levels of fishing mortality become high, variable recruitment can compound any declines that occur from exploitation and accelerate depletion. Furthermore, the recovery period for such stocks cannot usually be predicted with any level of confidence because it relies on the periodic, but irregular, occurrence of a good recruitment years which are not currently able to be predicted.

The current age structure of dhufish shows clear evidence of a high recruitment period that occurred during the four consecutive years from 1993 to 1997. This pulse has been maintaining the present high level of catches observed over the past few years which is dominated by fish aged 10 to 13 years. If no new recruitment pulse enters the fishery in the next year or so, once the current pulse is fished down it is likely that under present levels of fishing effort both the catch and catch rate will drop rapidly. If this occurs there will be a concomitant decline in the spawning biomass, which may affect the potential for strong recruitment in the future years.

Aside from the strong recruitment pulse, there is evidence of a substantial decline in the numbers of older fish during the past decade. The maximum observed age of dhufish has dropped 10 years from 41 to 31 years old, and the proportion of older dhufish (>13 year old) in the catch has decreased from 28% to 9%. This lack of older fish is indicative of recent depletion. It should be noted that while large fish are still being caught in the fishery, they are not necessarily old fish because length varies greatly with age. Length is not a good indicator of age, with a large dhufish of 900 mm total length possibly being anywhere from age 10 to more than 30 years due to growth slowing markedly after maturity and inherent variability in growth rate.

The decline in the adjusted wetline fishery catch rates in recent years is consistent with the estimates that current levels of fishing mortality are in excess of international benchmark standards (above the target, threshold or limit reference points depending upon the zone). In addition, recent experiments have revealed that post-release mortality for captured dhufish is the highest recorded for demersal species, reflecting their extreme susceptibility to barotrauma (21% mortality in waters 1-14 m, 86% mortality in water depths greater than 45 m).

The combination of high fishing mortality rates, sporadic recruitment, complex reproduction and susceptibility to barotrauma make dhufish especially vulnerable to the current level of fishing.

1.3 Pink snapper

Pink snapper have some of the same vulnerabilities to over-fishing as dhufish through their life history attributes, including a long life span (> 30 years), low rates of natural mortality, large size and age at maturity. In addition they form spawning aggregations that are predictable in time and space. While they can be successfully caught and released in shallow water, they suffer from the same level of post-release mortality from barotrauma as dhufish in deeper water (>40 m) so in those waters are not amenable to management measures that involve their capture and subsequent release (e.g. tags, changes to legal minimum sizes or bag limits).

A critical issue for pink snapper is that the large, predictable spawning aggregations targeted by fishers may result in continued high catch rates when the stock size is decreasing, which is known as hyperstability. Thus, the lack of change in their observed catch rates over recent years are affected by both hyperstability and the impacts of improved fishing technology. Consequently commercial wetline catch rates adjusted for improved fishing technology show declines over recent years indicating declining abundance rather than a stable population size. In addition, the only known significant spawning site within the West Coast Bioregion (located in Cockburn Sound/Warnbro Sound) is a highly industrial area that is already subject to high and increasing human usage. The pink snapper stock in this area therefore requires special protection.

While pink snapper are a long-lived species, most of the catch in the West Coast Bioregion is now comprised of individuals less than 10 years of age (except for Cockburn Sound). The dominant age classes in the north of the bioregion ranged from 3 to 6 years, with every individual reaching legal size by seven years. The dominant age classes in the south ranged from 5 to 8 years, with every individual reaching legal size by five years.

The assessment of the status of the pink snapper stocks indicate that the levels of fishing mortality for this species are well above international benchmark standards (substantially above limit reference points) across all zones of the West Coast Bioregion.

1.4 Baldchin groper

Baldchin groper are endemic to Western Australia and are found most abundant in the Abrolhos Island region. Biological information is available from Fairclough (2005) and Nardi *et al.* (2006). Assessment of the baldchin groper stocks on the West Coast revealed that the overall levels of fishing mortality were between target and threshold benchmarks. However, the level of fishing mortality at the Abrolhos Islands was above the threshold benchmark and combined with declining catch rates indicate that localised over-fishing is occurring.

1.5 Summary

The levels of exploitation on both 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 over-fished and therefore are being depleted to levels below those necessary to ensure their long-term sustainability. The current reliance of the dhufish catch on a single recruitment pulse together with the extremely truncated age distribution of pink snapper indicates that both these stocks are particularly vulnerable.

2.0 Introduction

Current growth in effective effort levels and exploitation of West Coast Demersal Scalefish stocks may be unsustainable and most stakeholders agree that intensive management of these stocks is a matter of urgent and growing importance. Preliminary research and anecdotal information indicate that localised depletion is becoming an increasing concern for key scalefish species, particularly in areas highly utilised by both the recreational and commercial fishing sectors.

Up to 100 species are taken in the West Coast Demersal Scalefish Fishery but important targets include the iconic West Australian dhufish (*Glaucosoma hebraicum*), pink snapper (*Pagrus auratus*) and baldchin groper (*Choerodon rubescens*). Because the species diversity is high, a strategy has been adopted by the Department of Fisheries, Western Australia, to select a number of specifically identified species to act as indicators for the whole system. By assessing the status of these indicator species and managing the effort in the fishery to maintain their sustainability, it is assumed that sustainable stocks of all other species exploited by the fishery will also be maintained.

The assessment task for the West Coast Demersal Scalefish Fishery becomes one of determining whether the fisheries for these indicator species can be considered sustainable at current levels of catch. Without an extended time series of good quality fisheries data the use of formal mathematical stock assessment models was not an option. The assessment framework adopted consisted of the following:

1. Determine the management and performance measures for the West Coast Demersal Scalefish Fishery.
2. Estimate the catch and effort in each of the zones from the fishing sectors involved in the fishery: commercial, recreational, and charter boat, and determine if there are any temporal and spatial trends in the catch and effort information.
3. Calculate catch rates and determine whether commercial catch-per-unit effort data could be improved, through a process of statistical standardisation, to be used as indices of abundance.
4. Use age-composition data to estimate the total and fishing mortality rates for the different indicator species in the different areas.
5. Explore the potential productivity of the species by investigating the growth and reproduction of the species (including size at age, size at maturity, spawning period and spawning variation).

2.1 Management and performance measures

The West Coast Demersal Scalefish Fishery extends south from the latitude 27°S around Cape Leeuwin and along the south coast to longitude 115°30'E. However, there is a proposal to extend the northern boundary to 26°30'S once a formal management plan for wetlining is introduced.

The demersal finfish resources in this bioregion are currently caught by the fishing groups:

- Commercial fishery, which is composed of the
  - Open access wetline (handline and dropline) fishery
  - Managed demersal gillnet and longline fisheries
  - Cockburn Sound fisheries
  - Bycatch by other fisheries
- Tour operator (Charter) fishery
- Recreational angling, mainly from boats
- Indigenous fishing with very limited data for this sector.

These fisheries extend over approximately 900 km of coastline and can be divided into the following main zones (Figure 1):

- Kalbarri zone (26°30'S – 28°S)
- Midwest zone (28°S – 31°S)
- Metropolitan (Metro) zone (31°S – 33°S)
- South zone (33°S – 115°30'E)
- Abrolhos Islands subregion

The Abrolhos Islands is not a formal zone, however it is treated as a separate subregion because of the nature of the suite of species in the area.

To progress the development of assessments for demersal scalefish species in the West Coast Bioregion the following key indicator species have been selected:

- Dhufish
- Pink snapper
- Baldchin groper

Dhufish and pink snapper have the highest single species landings in the commercial fishery and both are also extremely important recreational targets. The other indicator species identified was baldchin groper, which overall has relatively minor commercial catches but is an important commercial and recreational species around the Abrolhos islands. All species were suspected of having relatively vulnerable life histories which made them useful indicator species.

Breaksea cod (*Epinephelides armatus*) is an important recreational species but is considered a secondary indictor species and there are very limited data currently available and it was not possible to undertake a representative assessment at this time. As catches in deeper waters are currently relatively low and there is very limited data currently available; it was not possible to undertake an assessment on any of the prominent deepwater species at this time.

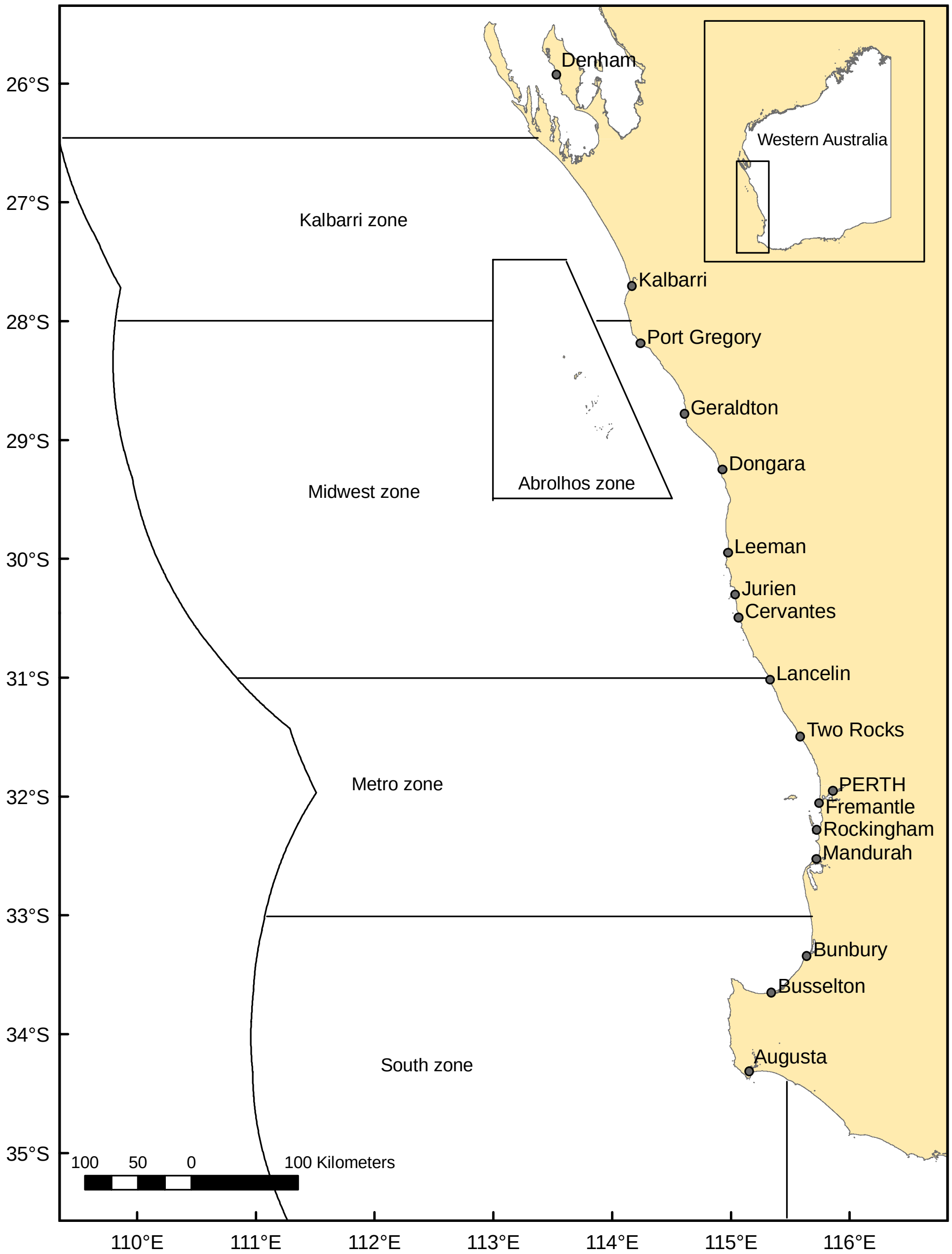


Figure 1. West Coast Bioregion showing the Kalbarri, Abrolhos, Midwest, Metro and South zones used in this report.

2.1.1 Spatial scales and species for management

Fishing pressure, relative species abundance and biological attributes may vary across the bioregion. In addition, recruitment relationships within the fishery are not known (*i.e.* whether eggs and larvae disperse evenly across the entire west coast population or are sourced locally). This raises questions about the best spatial and biological scales of management.

Taking into consideration the availability of research data, stock distribution and the iconic value of the different species in various regions, the determination of the status of the overall resource will be based on the status of the key species in the following areas of the West Coast Demersal Scalefish Fishery:

- The Kalbarri zone will be managed primarily on the basis of pink snapper sustainability
- Remaining regions which includes the Midwest, Metropolitan and South zones will be managed primarily on the basis of dhufish and pink snapper sustainability
- Abrolhos subregion will be managed primarily on the basis of baldchin groper sustainability

2.1.2 Performance measures

Performance measures can be based on current resource size and current exploitation in relation to the level when the population was unfished. Performance measures are based on target, threshold and limit reference points for resource size and exploitation (Figure 2). The target is the level where the stock biomass (B) and fishing mortality (F) should be, the threshold is a trigger for additional management and research actions, and the limit is where fishing must be very restricted or cease. Over-fished and over-fishing definitions are based on target, threshold and limit reference points for resource biomass and exploitation respectively (Figure 2).

While these represent the theoretical biological/management reference points, in the majority of cases the data required to calculate these measures will not always be available so alternative proxies, for example catch rates and catch, may need to be developed. Based on the biology of the species concerned, it is proposed that the performance measures in Table 1 should apply to the West Coast Demersal Scalefish Fishery. Managing to these target, threshold and limit reference points is consistent with international best practice (Caddy and Mahon 1998, Lembo 2006 and Walters and Martell 2002).

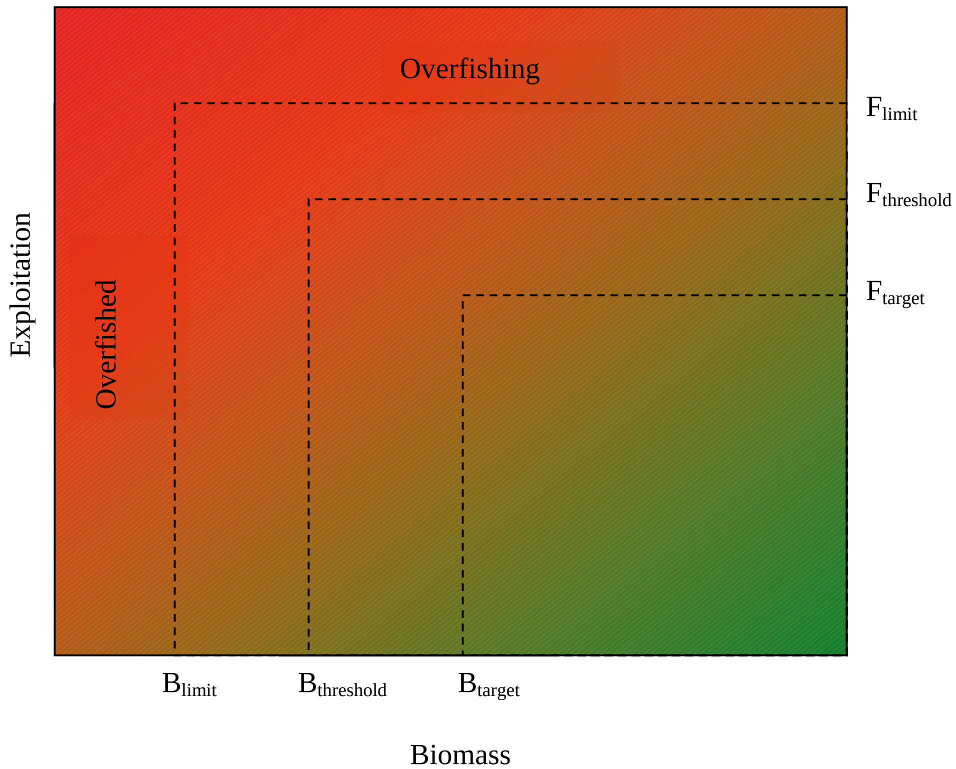


Figure 2. Over-fished and over-fishing definitions are based on target, threshold and limit reference points for resource biomass and exploitation respectively.

Table 1. Performance measures for resource biomass and exploitation target, threshold and limit reference points. B is the biomass estimate either as total biomass or spawning biomass (e.g. $B_{40\%}$ means the current biomass level is 40% of the unfished biomass level). *M* is natural mortality.

Available information Performance measure	**Biomass estimates (B)** (Provides for a performance measure of stock biomass and fishing pressure)	**Fishing mortality (F)** (Only provides for a performance measure of fishing pressure)	**Catch rate and/or catch estimates** (If threshold is reached management and research programs are initiated to provide estimates of biomass estimates and/or fishing mortality)
Target	$B_{40\%}$ (F at $B_{40\%}$)	M * 2/3	Within the range of the previous 5-10 years
Threshold	$B_{30\%}$ (F at $B_{30\%}$)	M	Outside the range of the previous 5-10 years
Limit	$B_{20\%}$ (F at $B_{20\%}$)	M * 2 for short-lived species (<10 years) M * 3/2 for long-lived species (>10 years)	NA

3.0 Catch and effort information for the indicator species

3.1 Introduction

The temporal and spatial distribution of the various West Coast Demersal fishing sectors appears to vary. Catch and effort information for the West Coast Demersal Scalefish indicator species (dhufish, pink snapper and baldchin groper) is available from commercial, charter and boat-based recreational fishers. These data are presented and trends apparent in the data are described.

3.2 Methods

3.2.1 Commercial catch and effort

Electronic commercial catch and effort data are available from compulsory logbooks for wetlining (handline, dropline, longline and gillnet) on the west coast from 1975. More recently longline and gillnet have been managed under the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery since 1988 and West Coast Demersal Gillnet and Longline (Interim) Managed Fishery since 1998. Catch and effort are available for Cockburn Sound (Line and Pot) and Cockburn Sound (Fish net) fisheries since 1995.

Fishers are required to submit compulsory monthly logbooks for aggregated monthly catch and effort information by fishing method used in each 1 degree by 1 degree block. Abrolhos blocks were instigated in 1992.

3.2.2 Charter catch and effort

Estimates of charter catch and effort are from the national survey (Henry and Lyle, 2003) carried out 2000/01 and from compulsory tour operator daily logbooks from 2002/03. It is uncertain whether the methods for calculating charter effort and catches, and hence results, of the national survey are comparable to those used in WA, so the results of the national survey are presented but not further considered here.

Tour operators are required to submit compulsory daily logbooks of catch and effort information for 5x5 nautical mile blocks since 2002.

3.2.3 Recreational catch and effort

Estimates of recreational catch and effort are from the national survey (Henry and Lyle, 2003) carried out in 2000/01, west coast boat ramp creel surveys carried out in 1996/97 and 2005/06, and a phone diary survey of west coast registered boats carried out in 2005/06. The methods for these surveys have now been developed and tested (Sumner and Williamson 1999, Henry and Lyle 2003). Catch and effort were calculated assuming that demersal fishing is carried out by ocean line fishing, consequently fishing trips in estuaries and fishing gears including pots and traps were omitted from the analyses. In addition recreational catch and effort were not fully estimated through the boat ramp creel survey for the Abrolhos zone as the survey did not to include visiting the Abrolhos Islands. However recreational catch and effort for the Abrolhos Islands would have been captured through interviews at boat ramps on the mainland.

It is uncertain whether the methods for calculating recreational effort and catches, and hence results, of the national survey are comparable to those used in WA, so the results of the national survey are presented but not further considered here. There were significant benefits gained by conducting the creel surveys and phone diary survey in the same year. The apparent precision (in terms of standard error of the estimate) of the creel surveys was better than that for the phone survey, however the estimates from both types of survey overlap in the majority of cases. In addition, creel estimates of catch and effort are available by 5x5 nautical mile blocks.

To ensure data confidentiality for commercial and charter fleets, information on the maps were presented as high, medium, low and very low based on logarithmic scales as shown below. The different colour schemes have been used so that data can be presented on different scales as appropriate (i.e. 0–0.1, 0–100, 0–1000, 0–10000 and 0–100000).

- 0.1 – 1
- 0.01 – 0.1
- 0.001 – 0.01
- 0 – 0.001

- 10 – 100
- 1 – 10
- 0.1 – 1
- 0 – 0.1

- 100 – 1000
- 10 – 100
- 1 – 10
- 0 – 1

- 1000 – 10000
- 100 – 1000
- 10 – 100
- 0 – 10

- 10000 – 100000
- 1000 – 10000
- 100 – 1000
- 0 – 100

3.3 Results and discussion

3.3.1 Fishing effort

Commercial fishing effort is dominated by the wetline sector (Figure 3). Handline and dropline effort in most zones increased from the mid 1970s to the late 1980s, before declining slightly during the mid 1990s (Figures 4-9). This effort then increased again in the late 1990s and remained at this level during the 2000s. In the Metro zone handline and dropline effort has increased consistently since the mid 1970s (Figure 7).

The introduction of formal management arrangements for demersal longline and gillnet fisheries under the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery and West Coast Demersal Gillnet and Longline Fishery reduced the commercial effort for these gears (Figures 3-8). However there are still fishers occasionally incorrectly identifying longline and gillnet as wetline gears. Gillnet is the dominant gear in these fisheries and constitutes a substantial portion of the total effort in the south zone.

The creation of distinct Abrolhos blocks in 1992 means that prior to this year it is uncertain what the individual commercial effort trends occurred in the Midwest and Abrolhos zones (Figures 5 and 6).

The introduction of the Cockburn Sound (Line and Pot and Fish Net) fisheries produced a consistent elevation in effort, especially during the 1990s, however commercial effort has decreased substantially during the 2000s (Figure 9).

From 2002/03 to 2005/06 there has been some expansion in the spatial distribution of commercial effort in both the wetline and demersal gillnet and longline fisheries (Figures 10 and 11).

The charter fisher days has decreased from 2002/03 to 2005/06 in all zones as the number of inactive licenses has increased (Figures 12-17). In 2005/06 the latent effort in the West Coast Bioregion was 39% of all licenses (*i.e.* inactive). However the trend in effort over that period differed between zones; in contrast to other zones effort in the Midwest zone has steadily increased since the initial decline in 2003/04. There appears to be some increased charter boat activity in 2005/06 around the northern regions, especially for Dongara and a slight contraction in the spatial distribution in southern regions (Figure 18).

Estimates of recreational effort were similar between the boat-ramp creel survey and the registered boat phone diary survey except in the Kalbarri zone (Figures 12-17). However, unlike most zones where sample sizes were greater than 50, sample sizes were very small for the Kalbarri (n=4) and Abrolhos (n=6) zones in the registered boat phone diary survey and hence estimates should be treated with caution. The boat-based recreational effort increased between the 1996/97 and the 2005/06 creel surveys. The estimated boat hours increased from 562,000 hours to 701,000 hours, similarly fisher hours increased from 1,348,000 to 1,557,000 (Figures 12-17). Between 1996/97 and 2005/06 the number of registered boats increased by 32% (DPI unpublished data) and consequently the proportion of boats actually fishing increased while the average persons per boat has remained steady. In 1996/97 the boat ramp based creel survey estimated that 58% of boats fished in the ocean with lines, with an average of 2.4 fishers onboard fishing for approximately 4.5 hours. In 2005/06, the boat ramp based creel survey estimated that 63% of boats fished in the ocean with lines, with an average of 2.3 fishers aboard fishing for approximately 5.3 hours. The spatial distribution of boat-based recreational effort has expanded considerably (Figure 19).

3.3.2 Dhufish catches

Commercial catches of dhufish increased between the mid 1970s to the mid 1980s before declining in the mid 1990s (Figure 20). Catches then increased again to a peak in 2002/03 254 tonnes, declining thereafter to be 203 tonnes in 2005/06. The average commercial catch for the last 10 years was 220 tonnes. Catches mainly come from the South, Metro, Midwest and Abrolhos zones. Dhufish are not important in Kalbarri and are very unlikely to be caught in Cockburn Sound. The wetline fishery produces the majority (>72% since 2000) of commercial dhufish catches in any given year with gillnet producing some catches especially in the South and Metro zones. There has been a small contraction in the spatial distribution of dhufish catches by the wetline fishery and an expansion in demersal gillnet and longline fisheries between 2002/03 and 2005/06 (Figures 21 and 22). Information provided by a wetline fisher estimates that the proportion of dhufish discarded was 21% in the Midwest zone between 2002 and 2006.

Charter catches have averaged 18 tonnes annually between 2002/03 and 2005/06 with most coming from the Metro zone followed by the Abrolhos and then the South zone (Figure 23). There has been offshore movement in the spatial distribution of dhufish catches in the southern zones and expansion in the northern zones between 2002/03 and 2005/06 (Figure 24). The numbers of dhufish released by charter has remained consistent between years with the average proportion released being 34% in Kalbarri, 17% in Abrolhos, 31% in Midwest, 38% in Metro and 21% in South zones.

The boat-based recreational catch of dhufish increased between the 1996/97 and 2005/06 surveys (Figure 25 and 26). In 2005/06 the total estimated boat-based recreational catch was 186 and 244 tonnes from the creel and phone diary surveys respectively. Catches mainly come from the South, Metro and Midwest zones with creel data not fully available for the Abrolhos. In each of these zones the boat-based recreational catches were greater than those of the commercial sector in 2005/06. In addition the spatial distribution of boat-based recreational dhufish catch has expanded considerably between 1996/97 and 2005/06 (Figure 27). Dhufish released by boat-based recreational activity in 2005/06 was 25% in Kalbarri, 25% in the Midwest, 38% in the Metro and 34% in the South zone.

3.3.3 Pink snapper catches

Commercial catches of pink snapper increased between the mid 1970s to mid 1980s (Figure 28). Since the early 1980s pink snapper have undergone three long term cycles of catches, initially peaking at 523 tonnes in 1988/89 and subsequently peaking at 366 tonnes in 1995/96 and 356 tonnes in 2003/04 tonnes . Whether these approximately 7-8 year cycles relate to strong year classes sequentially entering the fishery and being fished down or to some other reason is unknown, but it is clear that pink snapper catches are not typically stable over this period.

Catches mainly come from the Kalbarri and Abrolhos zones with smaller catches from the Midwest, Metro and South zones. The wetline fishery makes up the majority (>78% since 2000) of pink snapper catches in any given year with gillnet producing some catches. Cockburn Sound (and including neighbouring Warnbro Sound) is a special sub-region because it is an important spawning area for snapper on the West Coast. Commercial catches in the Cockburn sound reached as high as 12 tonnes in 2002/03 but a spawning season closure was introduced with less than one tonne per year now taken commercially.

There has been a small expansion in the spatial distribution of pink snapper catches by the demersal gillnets and demersal longline fisheries remained similar in wetline fishery between 2002/03 and 2005/06 (Figures 29 and 30).

Charter catches of snapper have averaged 17 tonnes between 2002/03 and 2005/06 with most coming from the Metro and Abrolhos zones (Figure 31). There has been an offshore movement in the spatial distribution of pink snapper catches in the southern zones and marginal expansion in the northern zones between 2002/03 and 2005/06 (Figure 32). The numbers of pink snapper released by charter boats has remain consistent between years with the average proportion released being 54% in Kalbarri, 28% in Abrolhos, 36% in Midwest, 34% in Metro and 9% in South zones.

The boat-based recreational catch of pink snapper increased between the 1996/97 and 2005/06 surveys (Figures 33 and 34). In 2005/06 the total estimated boat-based recreational catch was 40 and 60 tonnes from the creel and phone diary surveys respectively. Catches mainly come from the South, Metro and Midwest zones with creel data not fully available for the Abrolhos. In all zones, the boat-based recreational catches were substantially lower than those of the commercial sector in 2005/06. In addition the spatial distribution of boat-based recreational pink snapper catch has expanded considerably between 1996/97 and 2005/06 (Figure 35). Pink snapper released by boat-based recreational activity in 2005/06 was 48% in Kalbarri, 32% in Midwest, 54% in Metro and 34% in South zones.

3.3.4 Baldchin groper catches

Commercial catches of baldchin groper increased between the mid 1970s to late 1980s before declining in the early 1990s and remaining stable thereafter (Figure 36). The average commercial catch for the last 10 years was 39 tonnes. Catches mainly come from the Midwest and Abrolhos zones with small catches from the Metro and Kalbarri zones. The wetline fishery makes up the majority (>55% since 2000) of baldchin groper catches in any given year with gillnets producing substantial catches especially in the South and Metro zones. There has been a small offshore expansion in the spatial distribution of baldchin groper catches by the wetline fishery and demersal gillnet and demersal longline fisheries between 2002/03 and 2005/06 (Figures 37 and 38).

Charter catches have averaged 7 tonnes between 2002/03 and 2005/06 with most coming from the Abrolhos zone (Figure 39). There has been contraction in the spatial distribution of baldchin groper catches in the southern zones and marginal in the northern zones between 2002/03 and 2005/06 (Figure 40). The numbers of baldchin groper released by charter operations has remain consistent between years with average proportion released being 38% in Kalbarri, 23% in Abrolhos, 21% in Midwest, 10% in Metro and 8% in South zones.

The boat-based recreational catch of baldchin groper increased between the 1996/97 and 2005/06 surveys (Figures 41 and 42). In 2005/06 the total estimated boat-based recreational catch was 28 and 62 tonnes from the creel and phone diary surveys respectively. Catches mainly come from the Midwest zones with creel data not fully available for the Abrolhos. The boat-based recreational catches were equal to or double those of the commercial sector in 2005/06. In addition, the spatial distribution of boat-based recreational baldchin groper catch has expanded considerably between 1996/97 and 2005/06 (Figure 43). The numbers of baldchin groper released by boat-based recreational activity in 2005/06 was 22% in Kalbarri, 18% in Midwest, 10% in Metro and 0% in South zones.

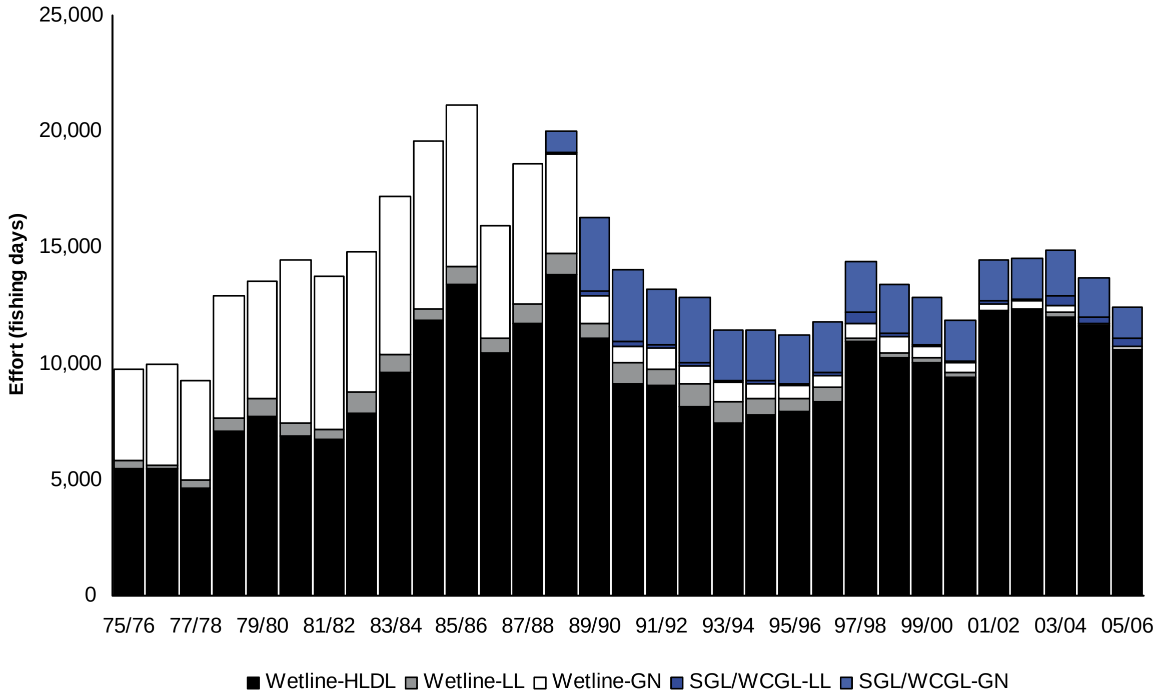


Figure 3. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the West Coast Bioregion. See methods for details of fishery and gear descriptions.

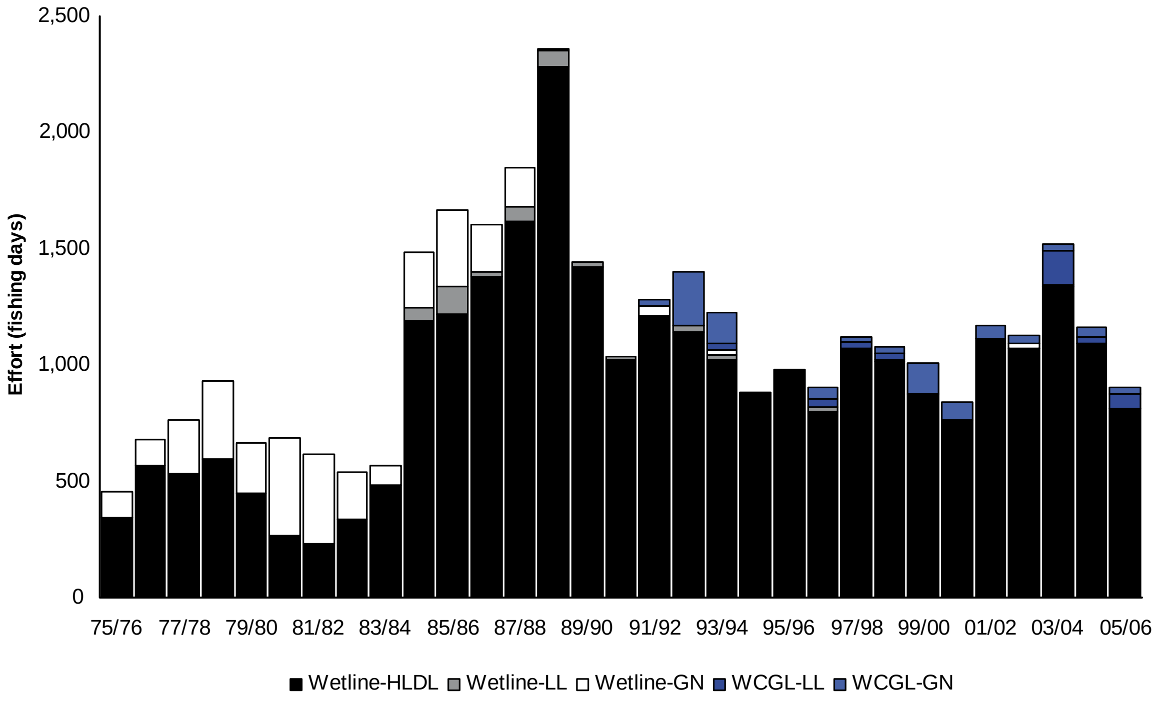


Figure 4. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the Kalbarri zone. See methods for details of fishery and gear descriptions.

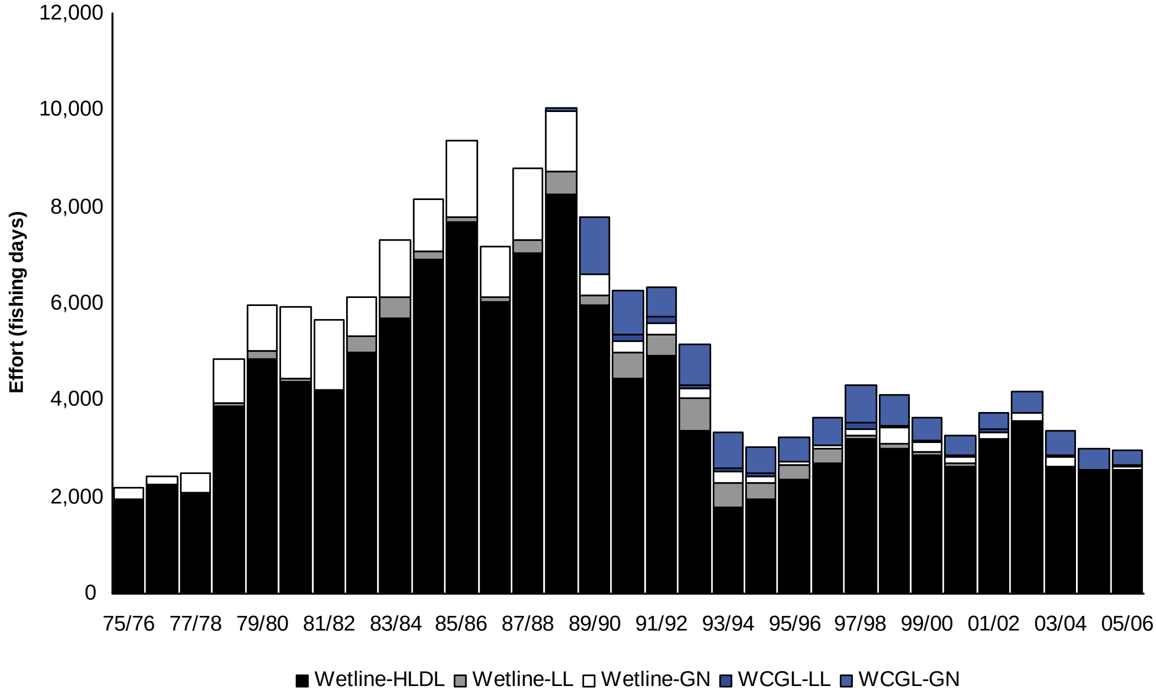


Figure 5. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the Midwest zone. See methods for details of fishery and gear descriptions.

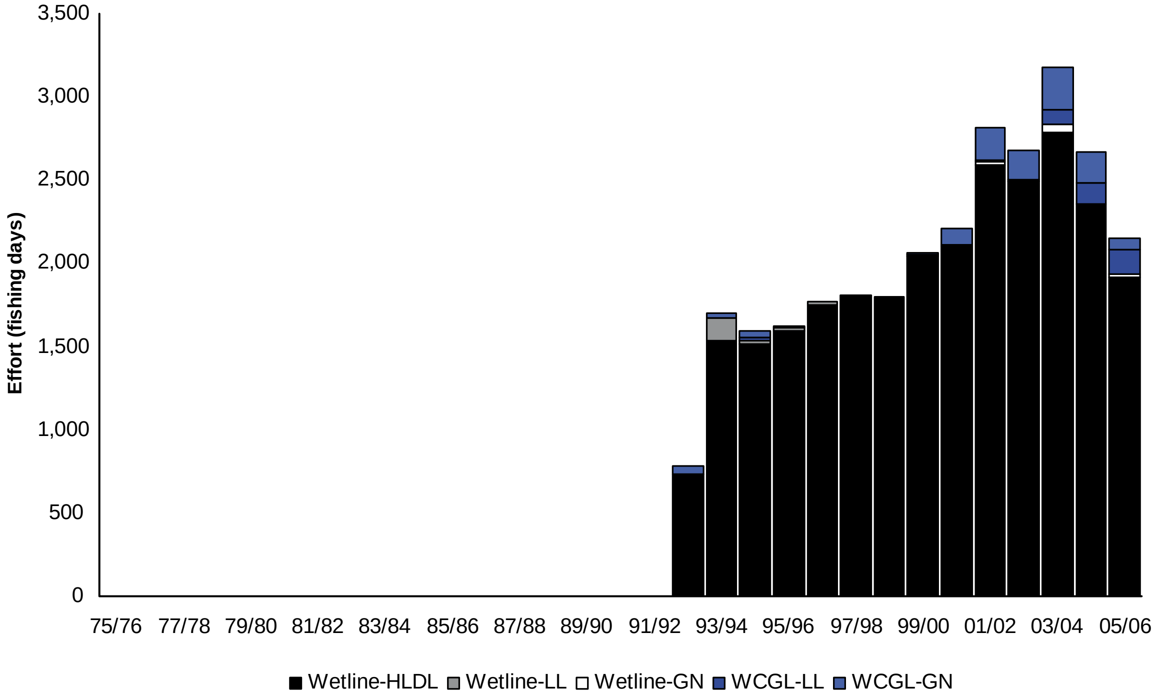


Figure 6. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the Abrolhos zone. See methods for details of fishery and gear descriptions.

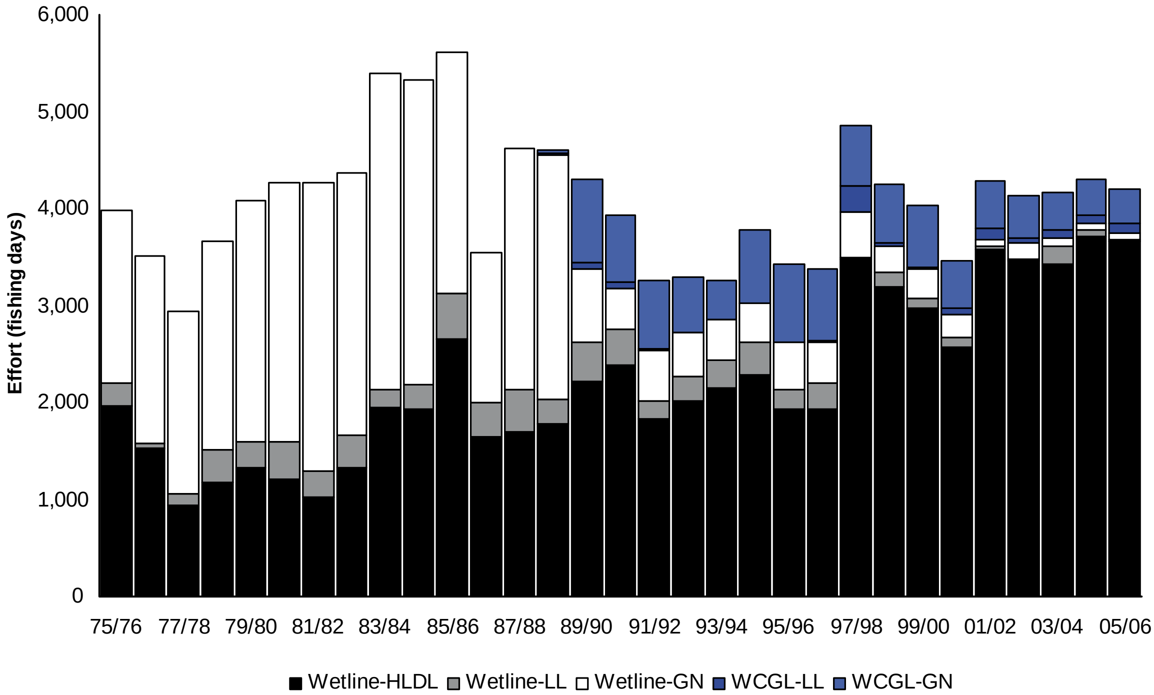


Figure 7. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the Metro zone. See methods for details of fishery and gear descriptions.

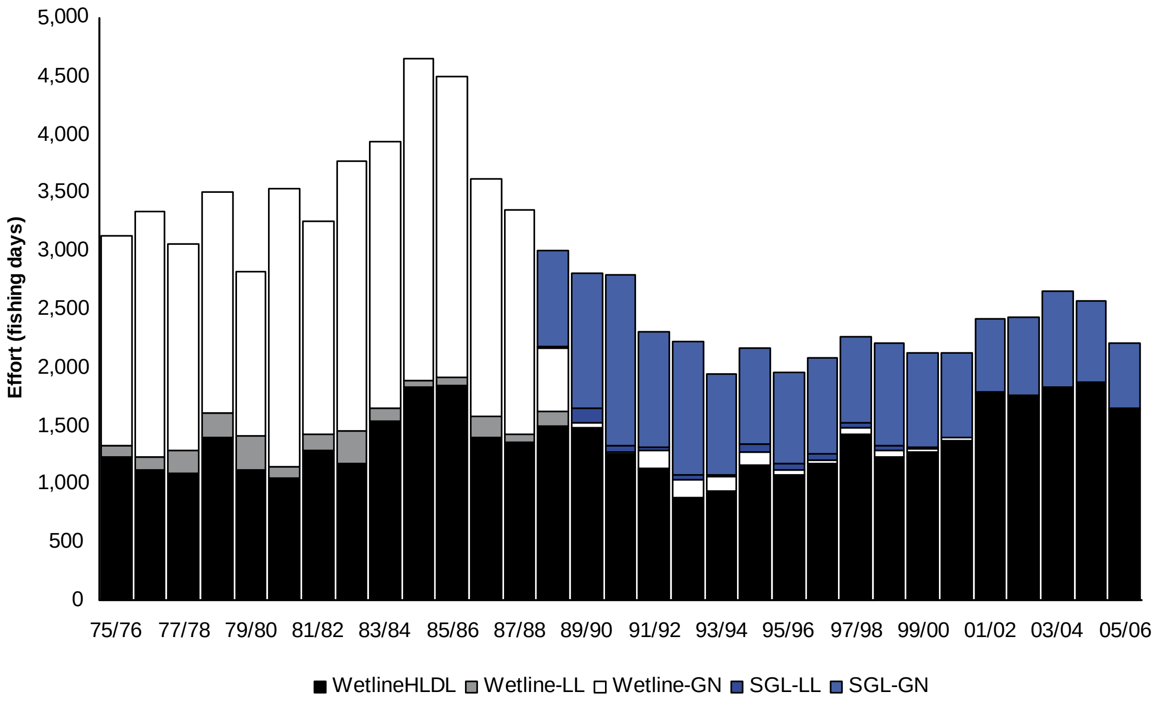


Figure 8. Commercial wetline and demersal gillnet and demersal longline fisheries effort in the South zone. See methods for details of fishery and gear descriptions.

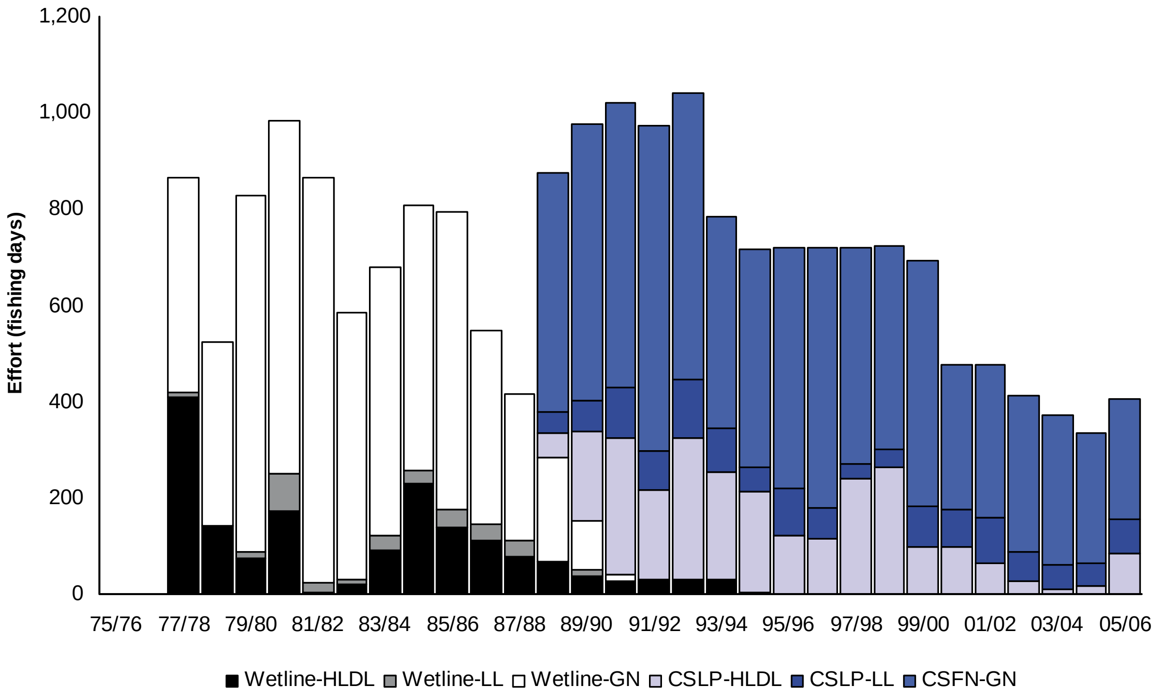


Figure 9. Commercial wetline, Cockburn Sound (Line and Pot) and Cockburn Sound (Fish net) fisheries effort in Cockburn Sound. See methods for details of fishery and gear descriptions.

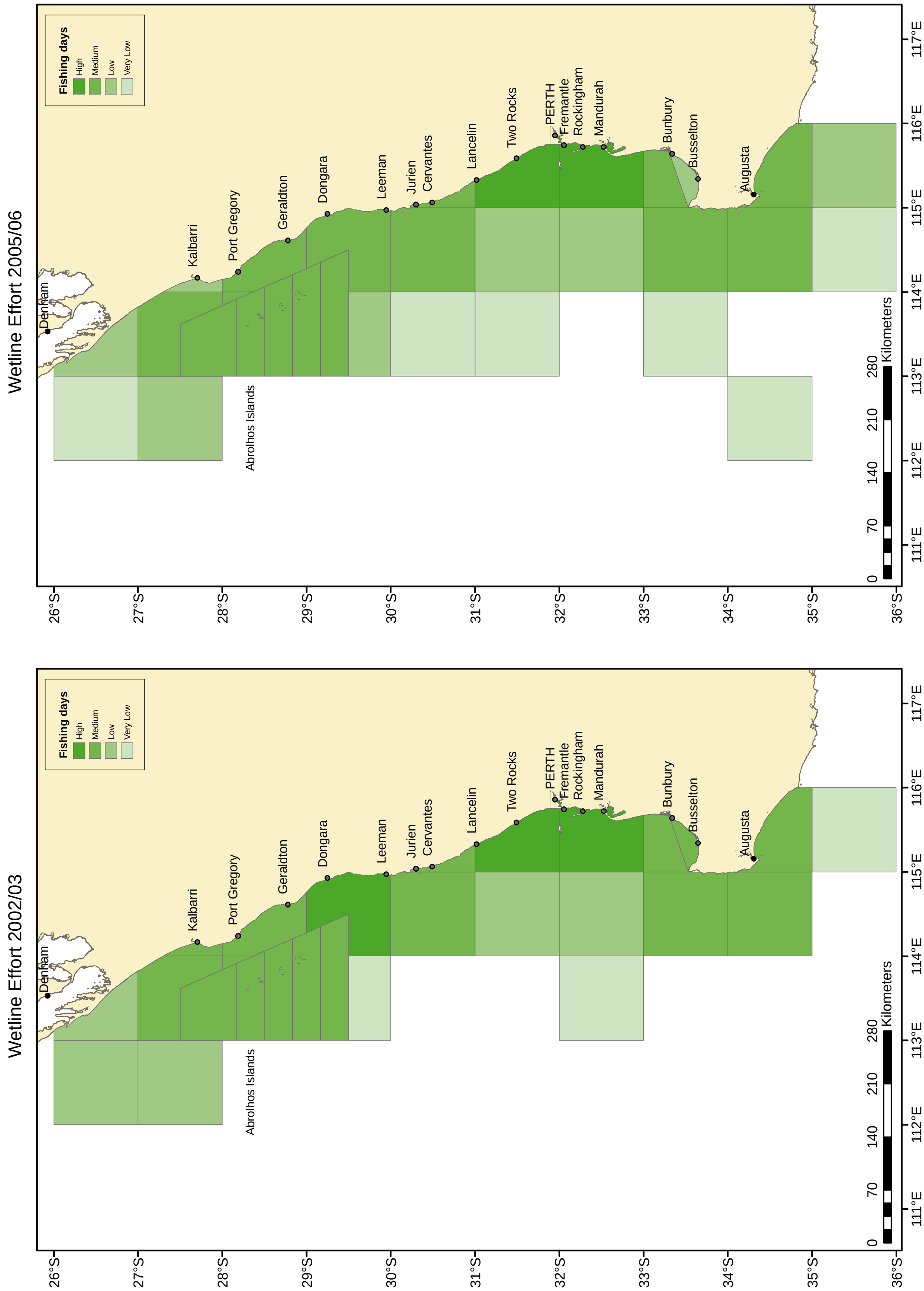


Figure 10. Commercial wetline (handline and dropline) effort in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear.

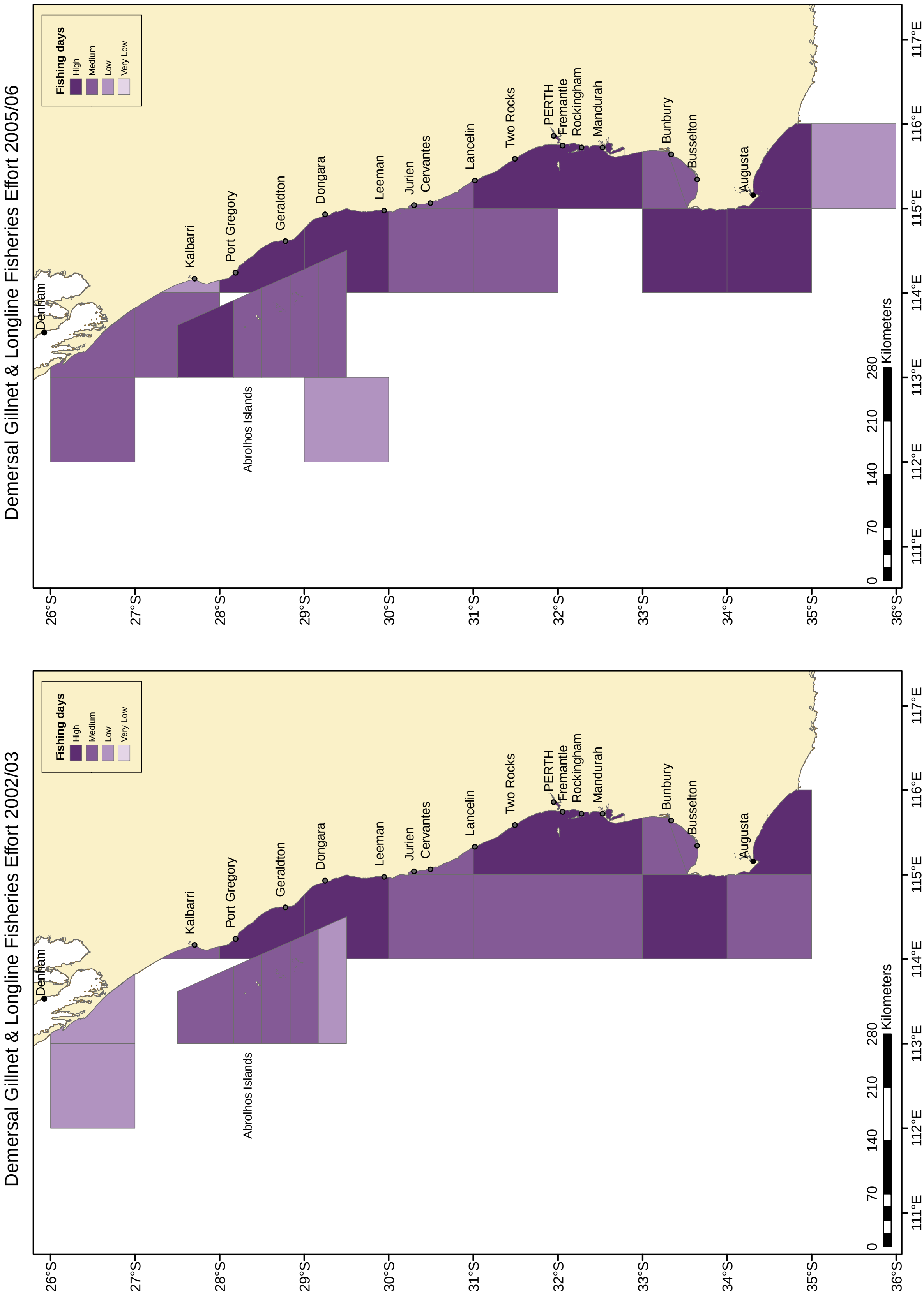


Figure 11. Commercial demersal gillnet and demersal longline fisheries effort in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

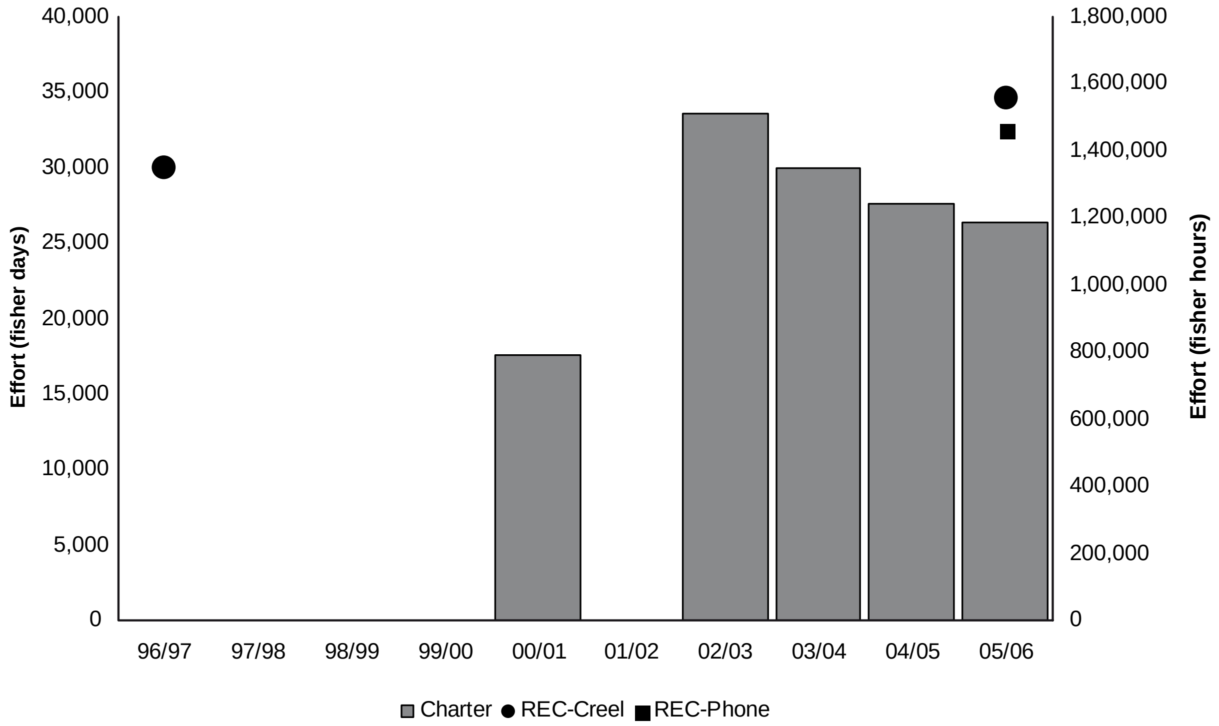


Figure 12. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in West Coast Bioregion. The 2000/01 data is from a national phone-diary survey. See methods for details of fishery and gear descriptions.

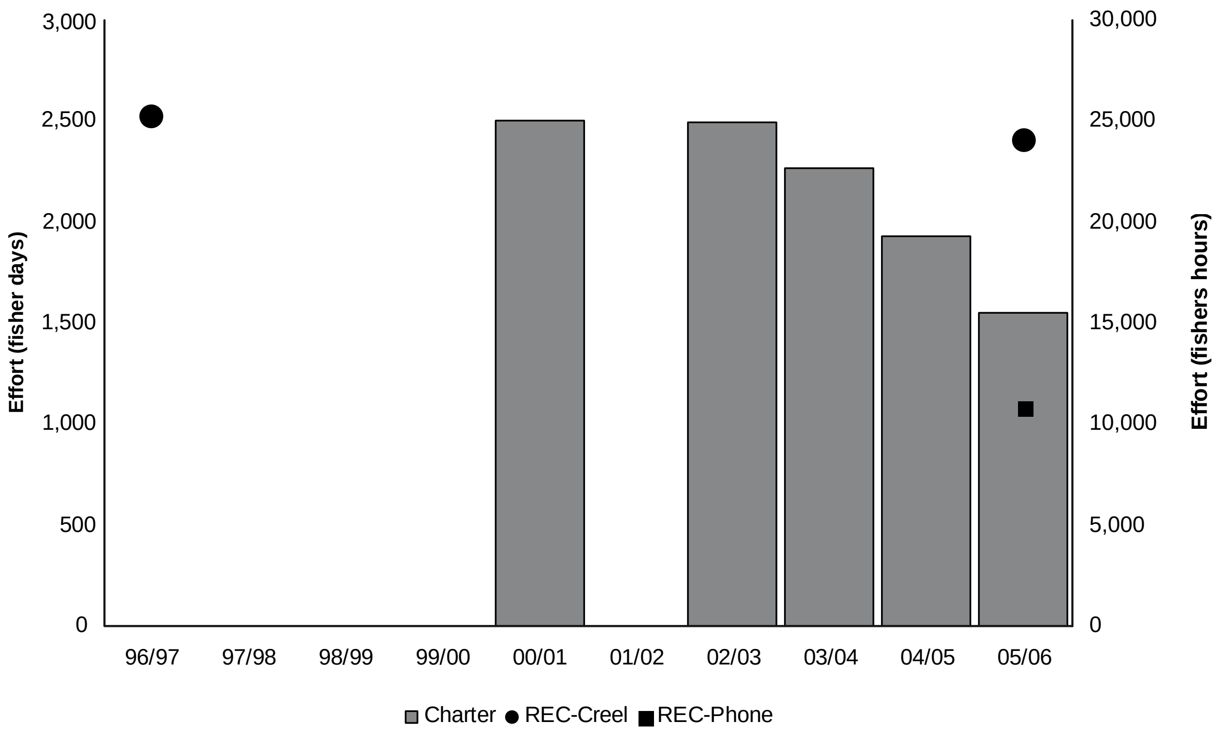


Figure 13. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in Kalbarri zone. The 2000/01 data is from a national phone-diary survey. See methods for details of fishery and gear descriptions.

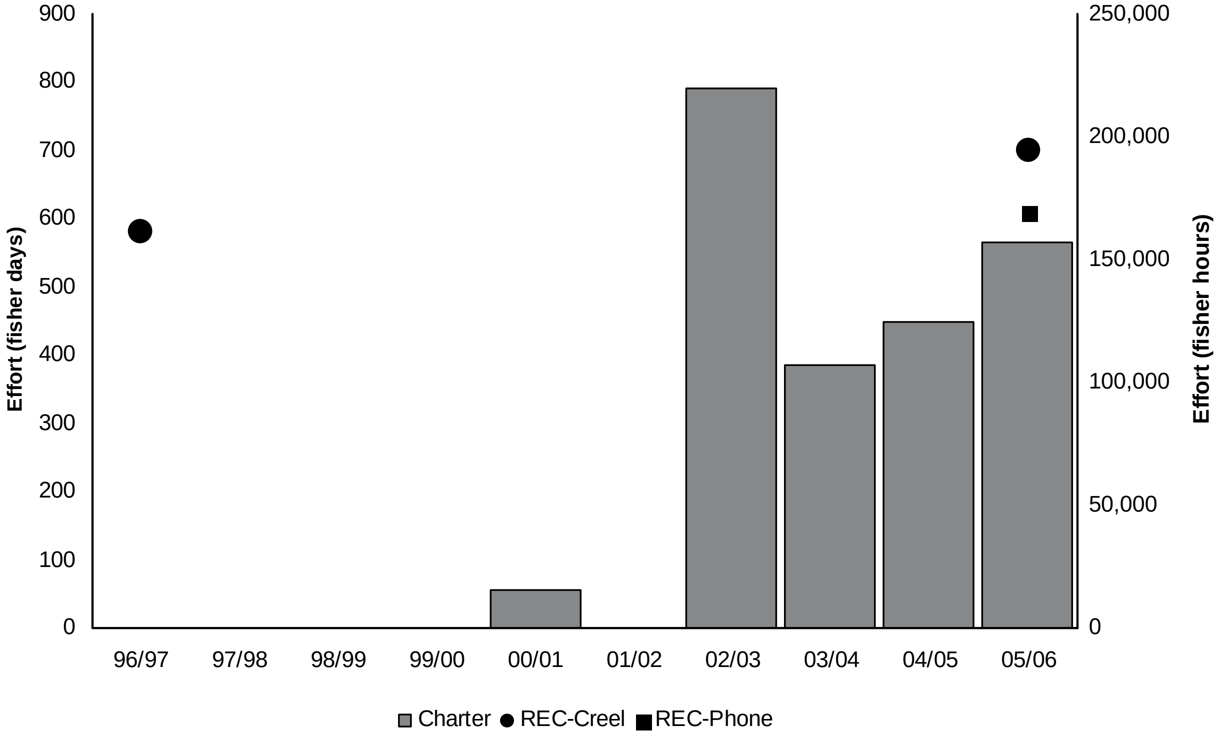


Figure 14. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in Midwest zone. The 2000/01 data is from a national phone-diary survey. See methods for details of fishery and gear descriptions.

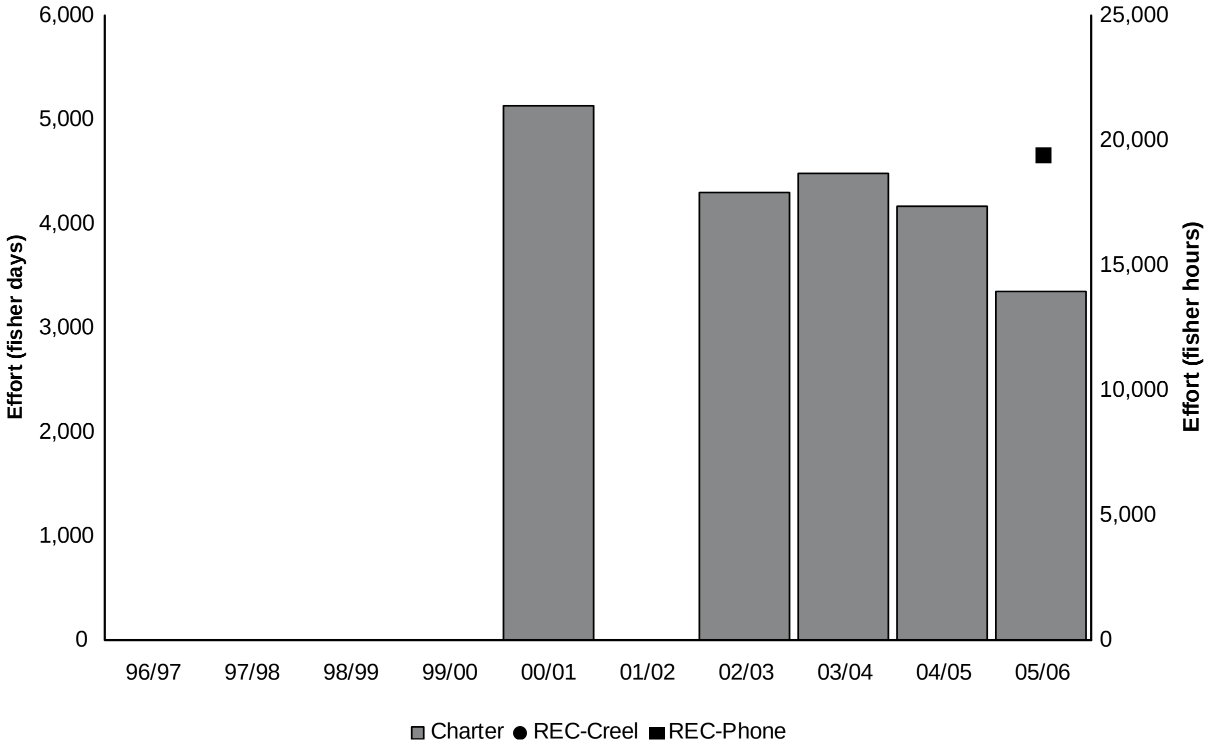


Figure 15. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in Abrolhos zone. The 2000/01 data is from a national phone-diary survey. See methods for details of fishery and gear descriptions.

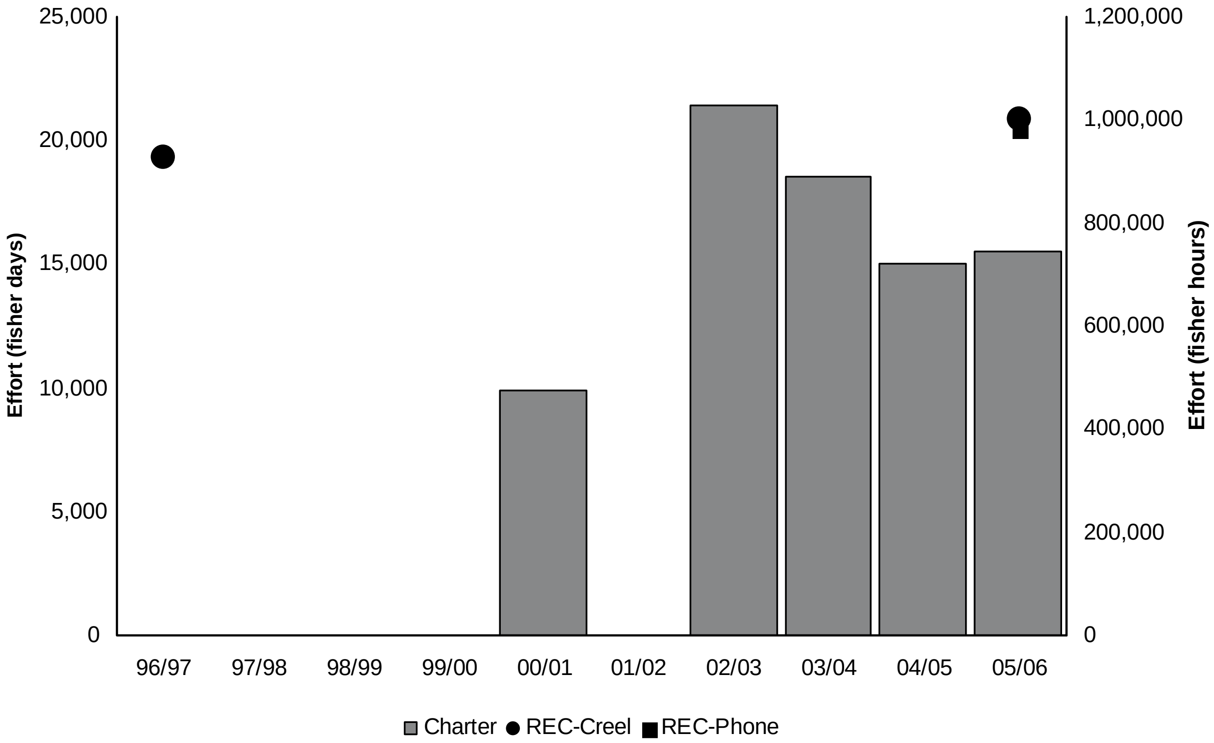


Figure 16. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in Metro zone. The 2000/01 data is from a national phone-diary survey. See methods for details of fishery and gear descriptions.

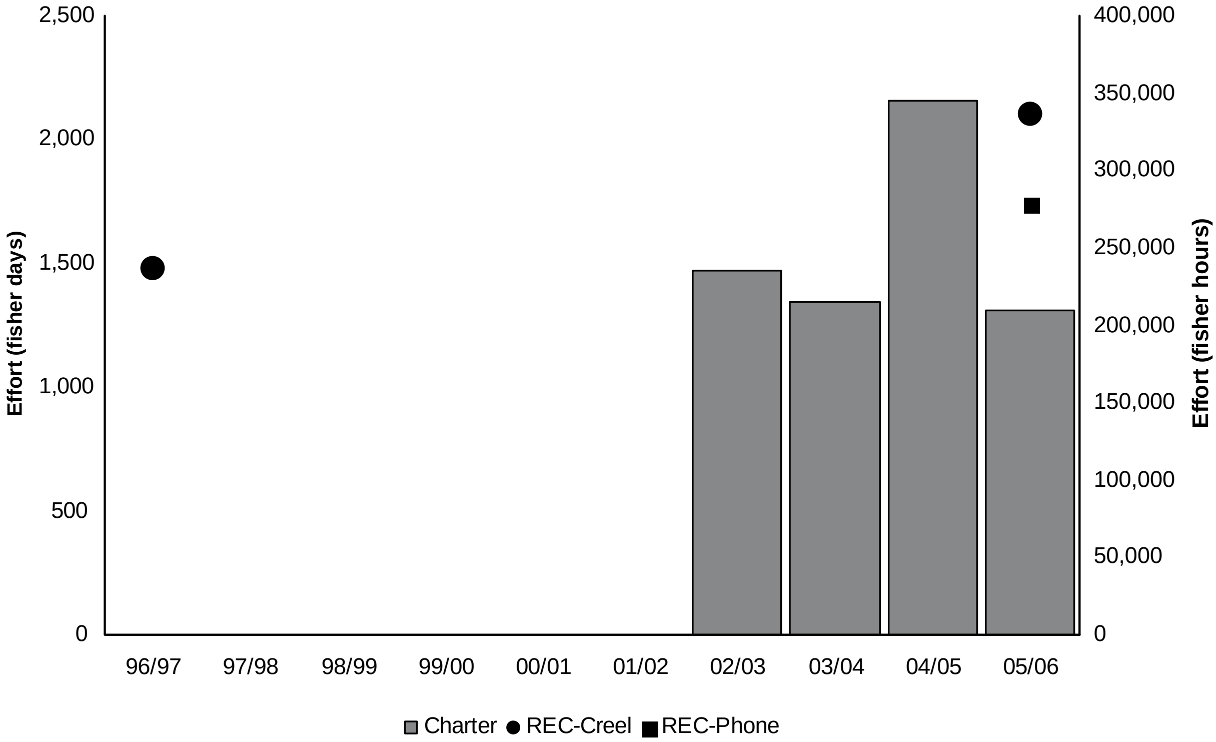


Figure 17. Tour Operator (Charter - fisher days) and recreational effort (fisher hours) in South zone. See methods for details of fishery and gear descriptions.

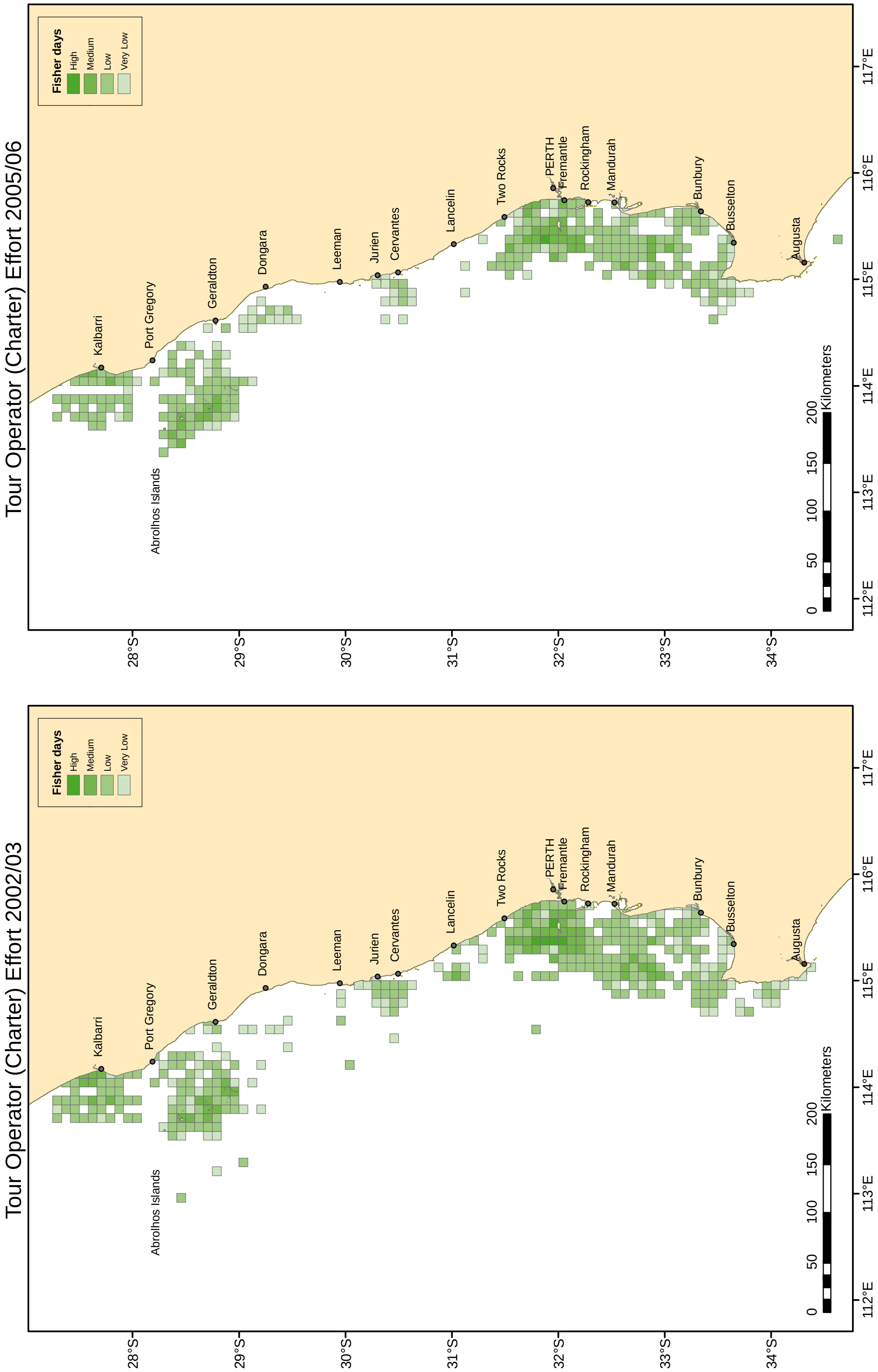


Figure 18. Tour operator (Charter) effort in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

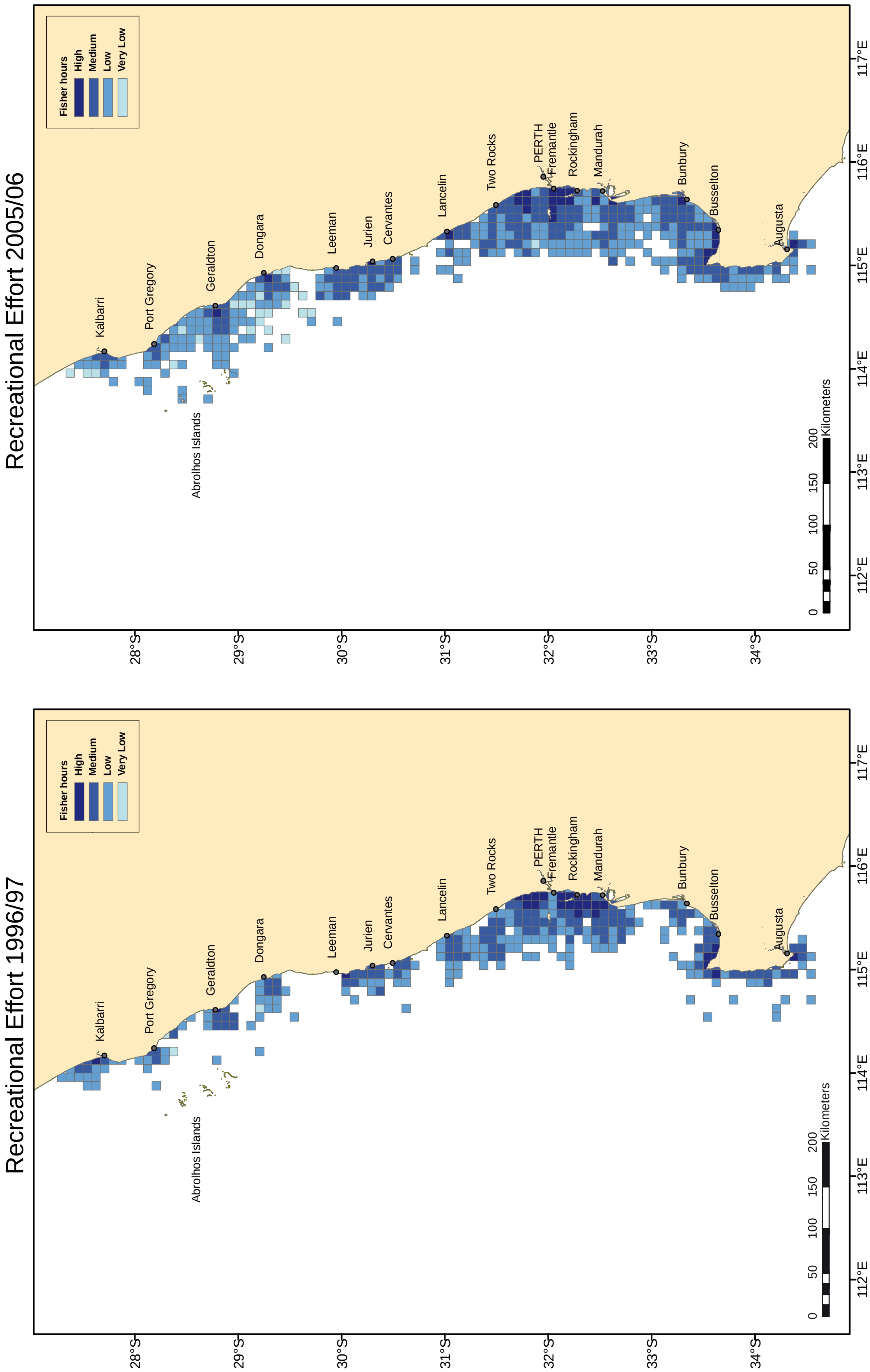


Figure 19. Estimated boat-based recreational effort using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

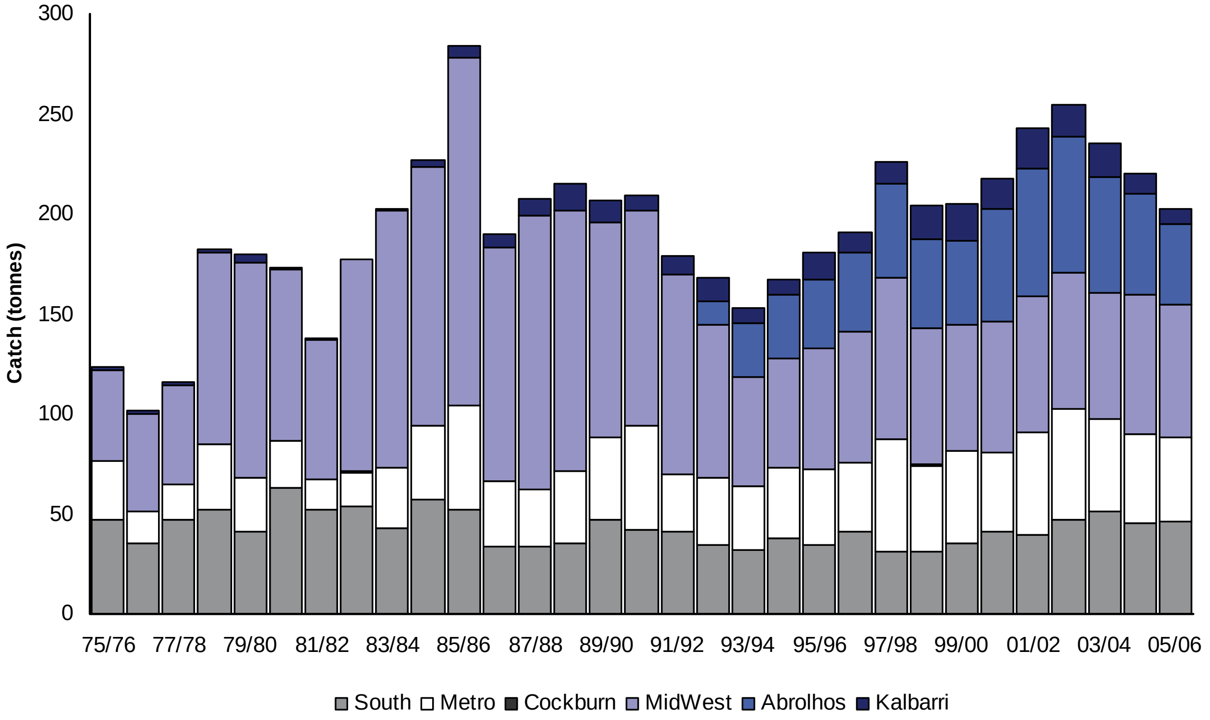
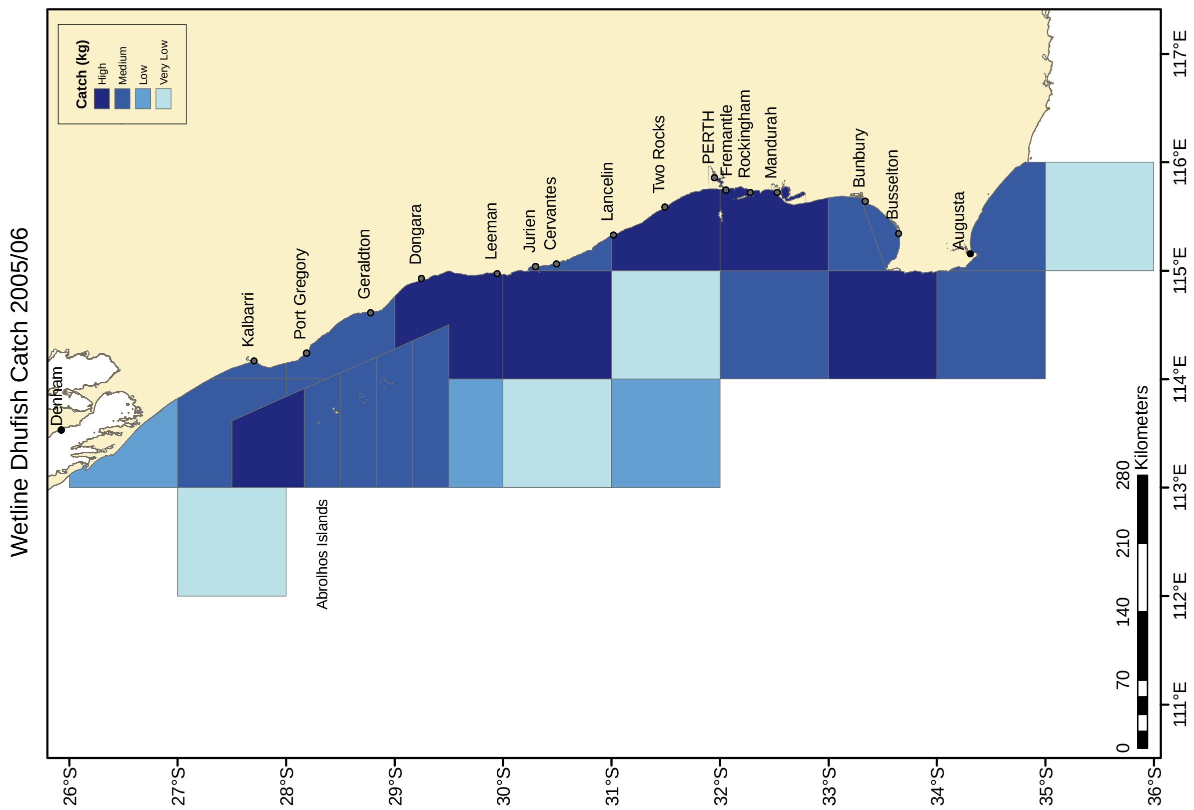


Figure 20. Commercial dhufish catch by wetline and demersal gillnet and demersal longline fisheries in each zone. See methods for details of zones, fishery and gear description.



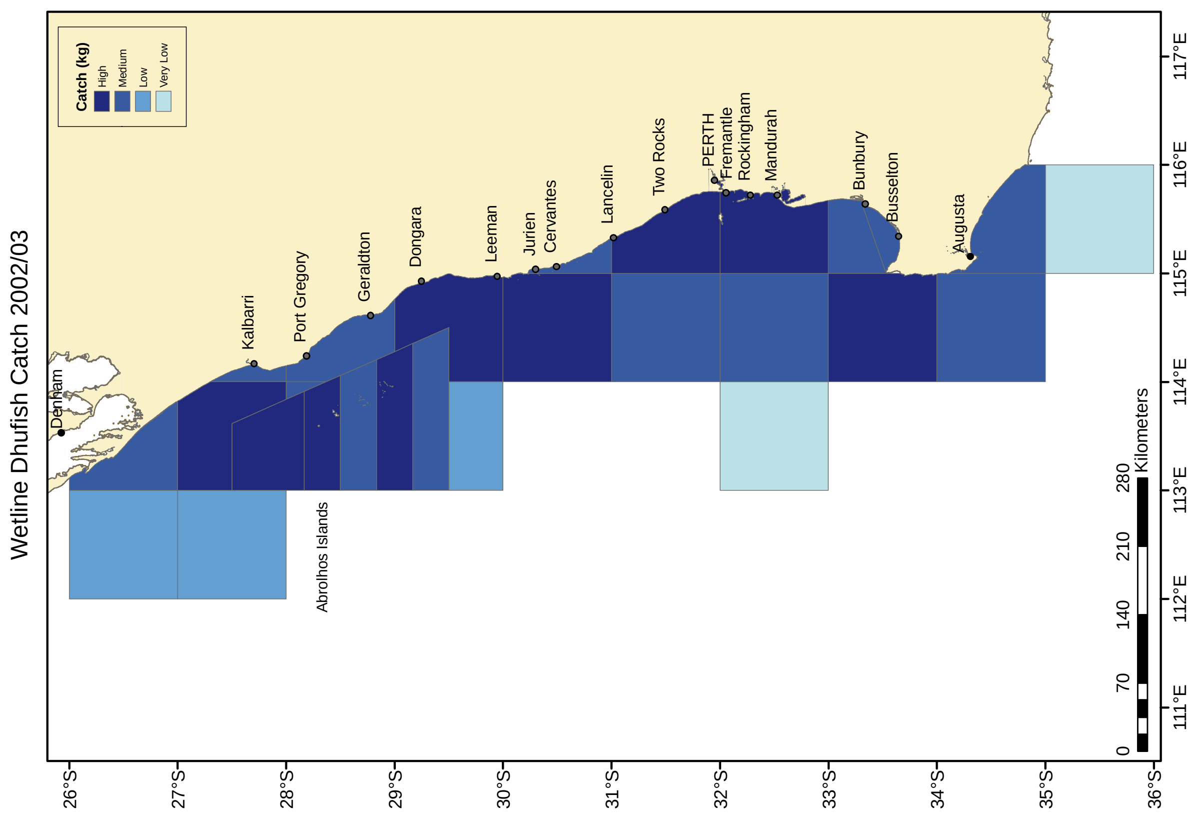


Figure 21. Commercial wetline (handline and dropline) dhufish catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

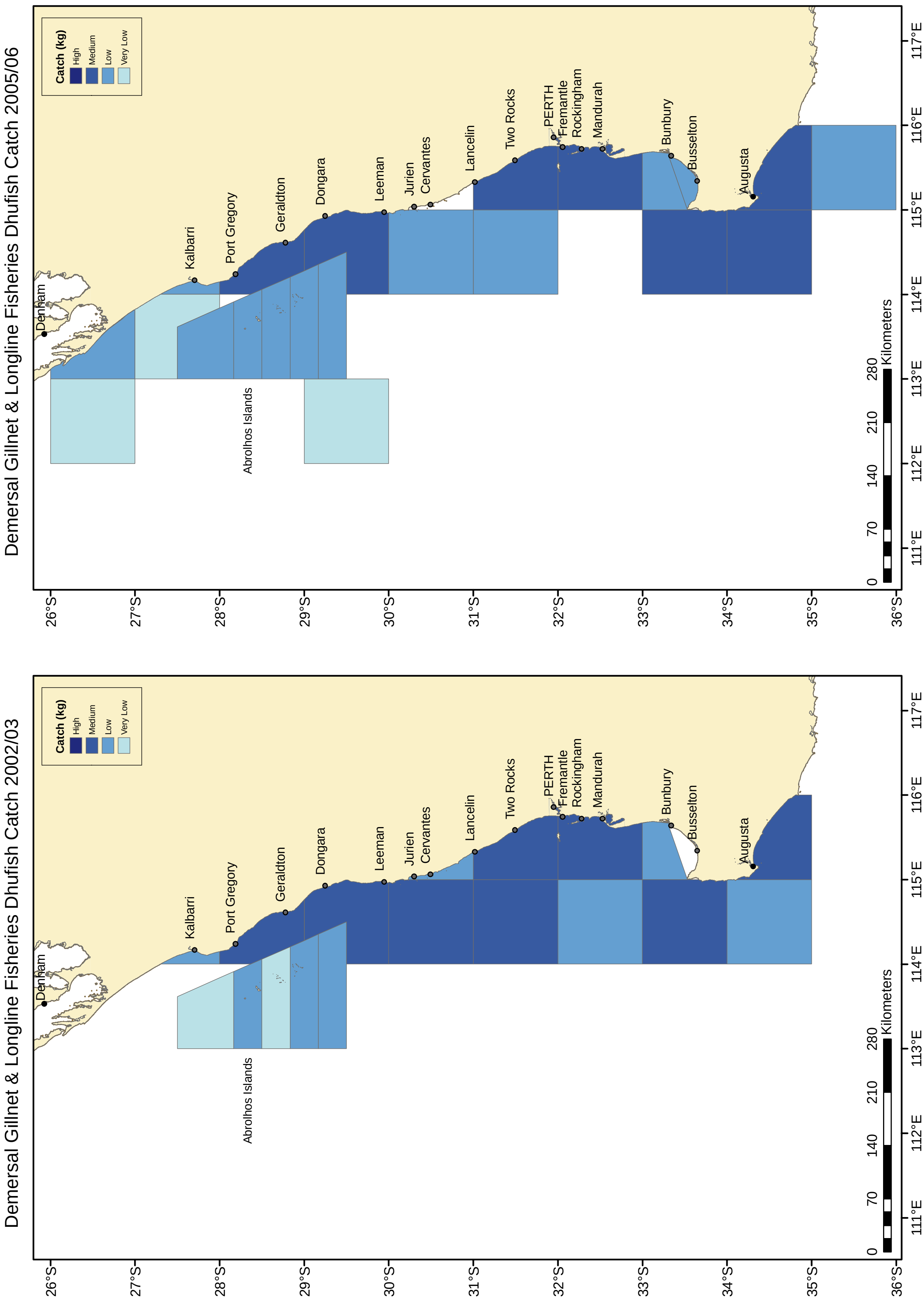


Figure 22. Commercial demersal gillnet and demersal longline fisheries dhufish catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

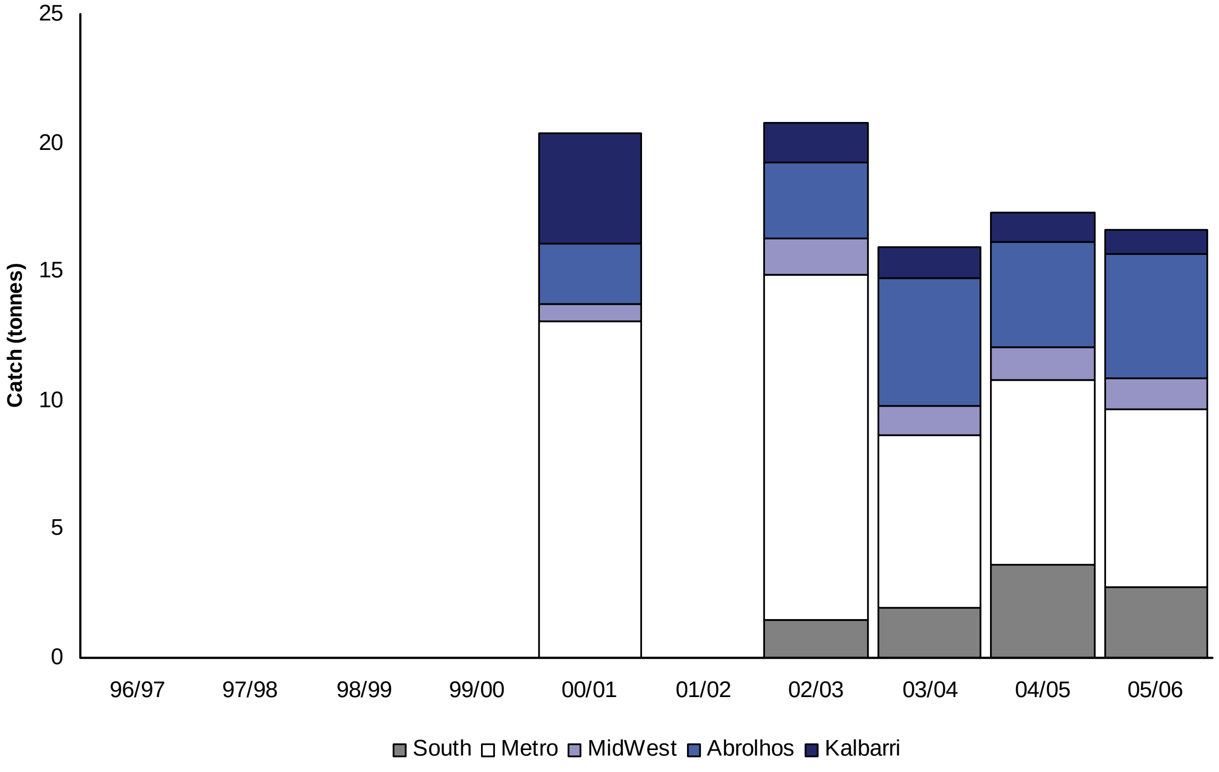
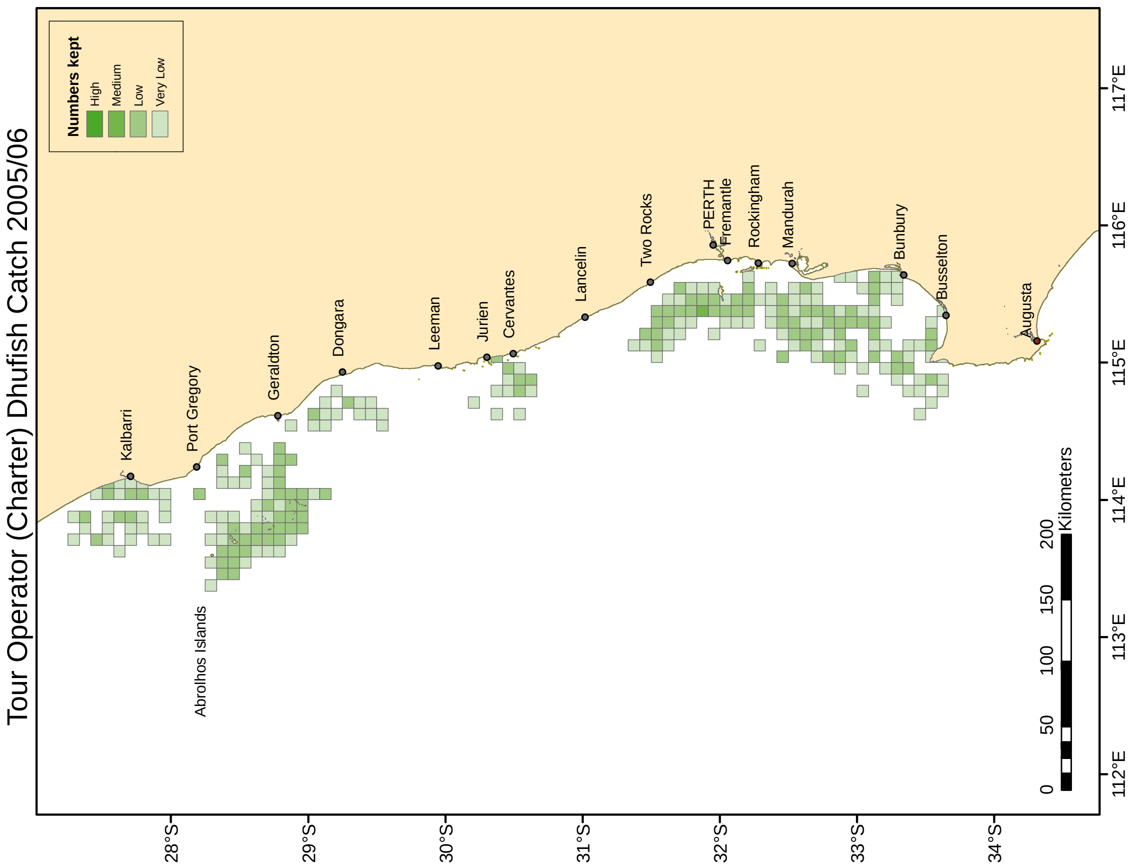


Figure 23. Tour Operators (Charter) dhufish catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and fishery descriptions.



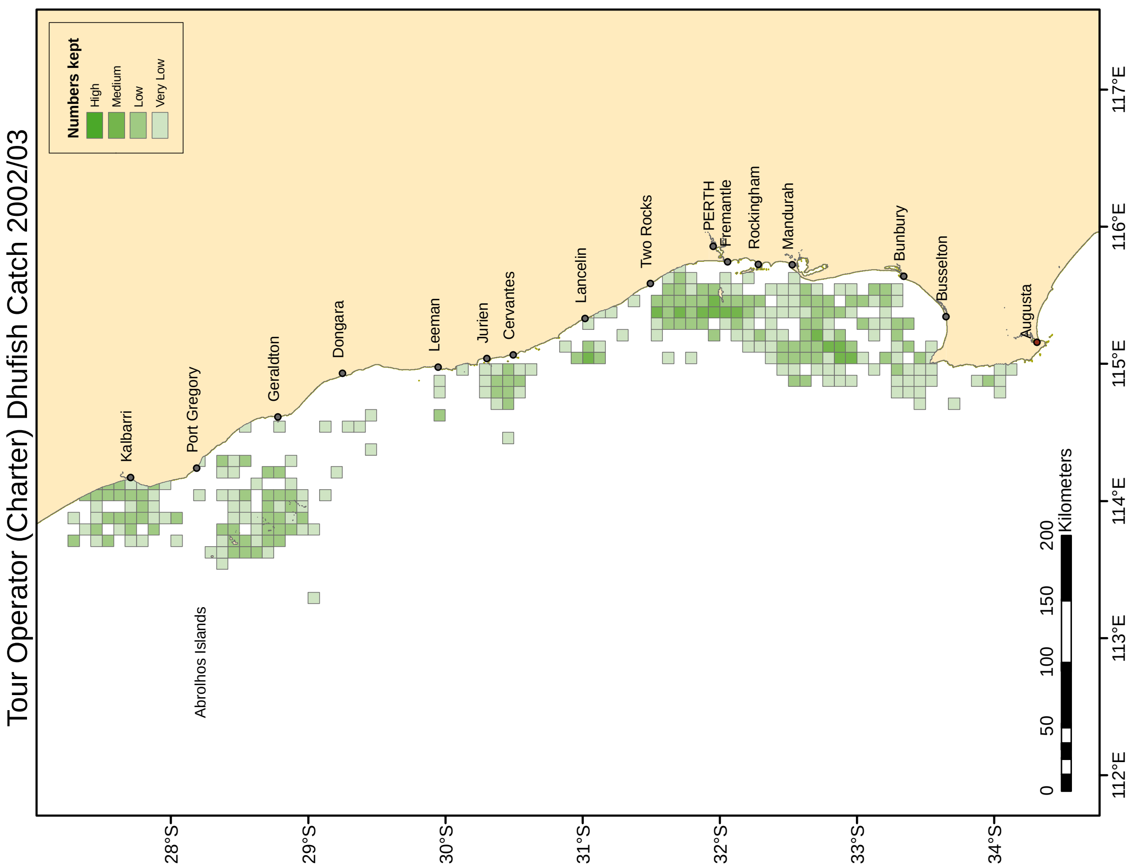


Figure 24. Tour operator (Charter) dhufish catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

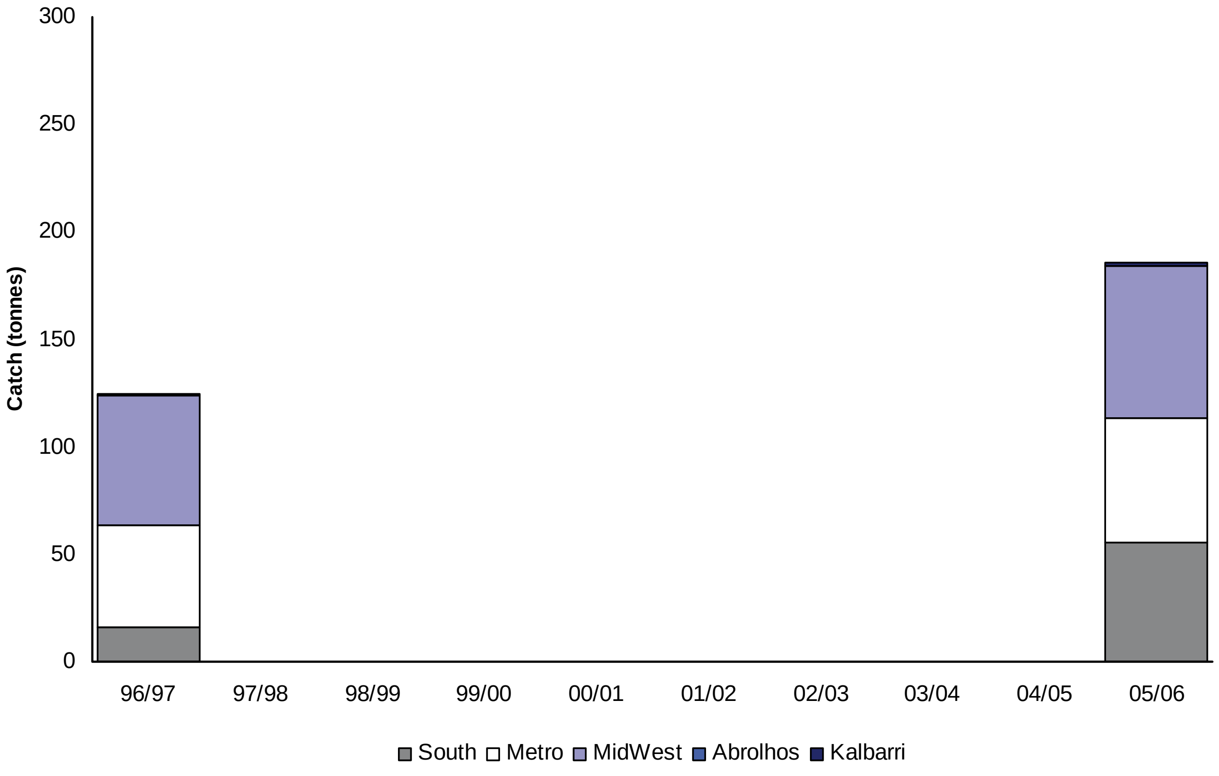


Figure 25. Estimated recreational (boat ramp creel survey) dhufish catch in each zone. See methods for details of zones and survey descriptions.

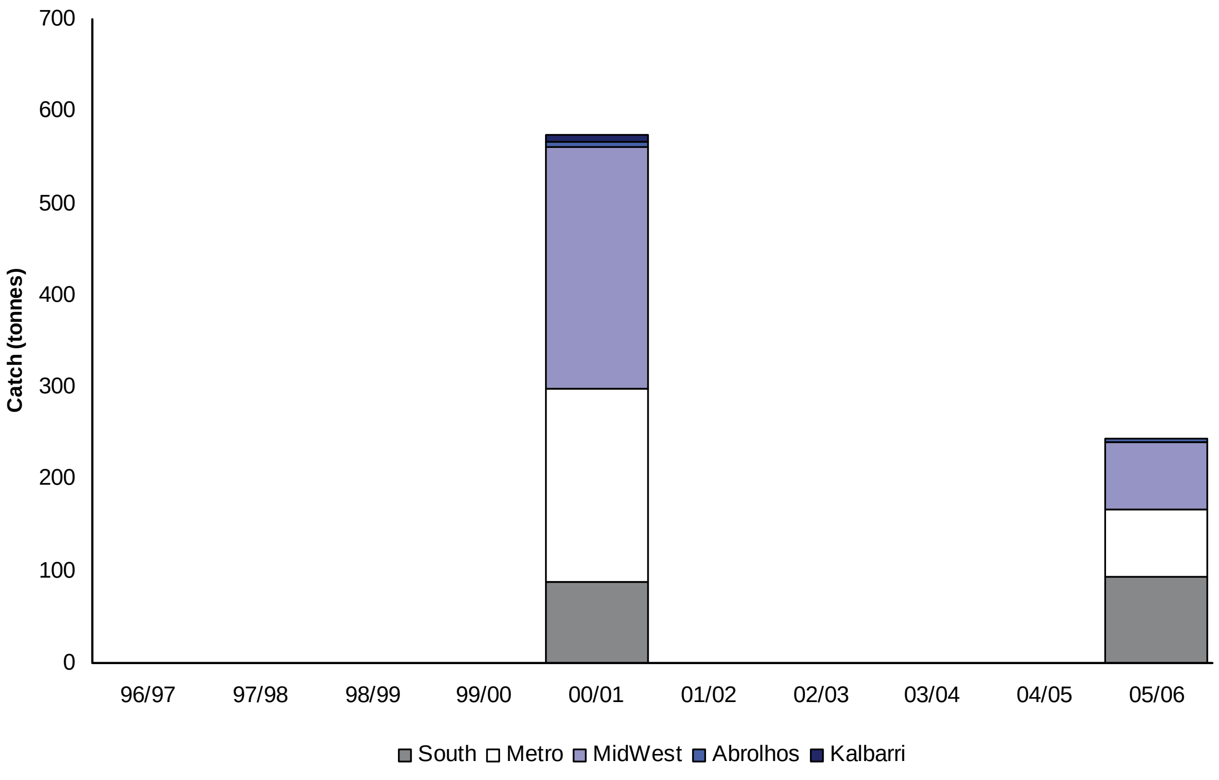


Figure 26. Estimated recreational (phone-diary survey) dhufish catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and survey descriptions.

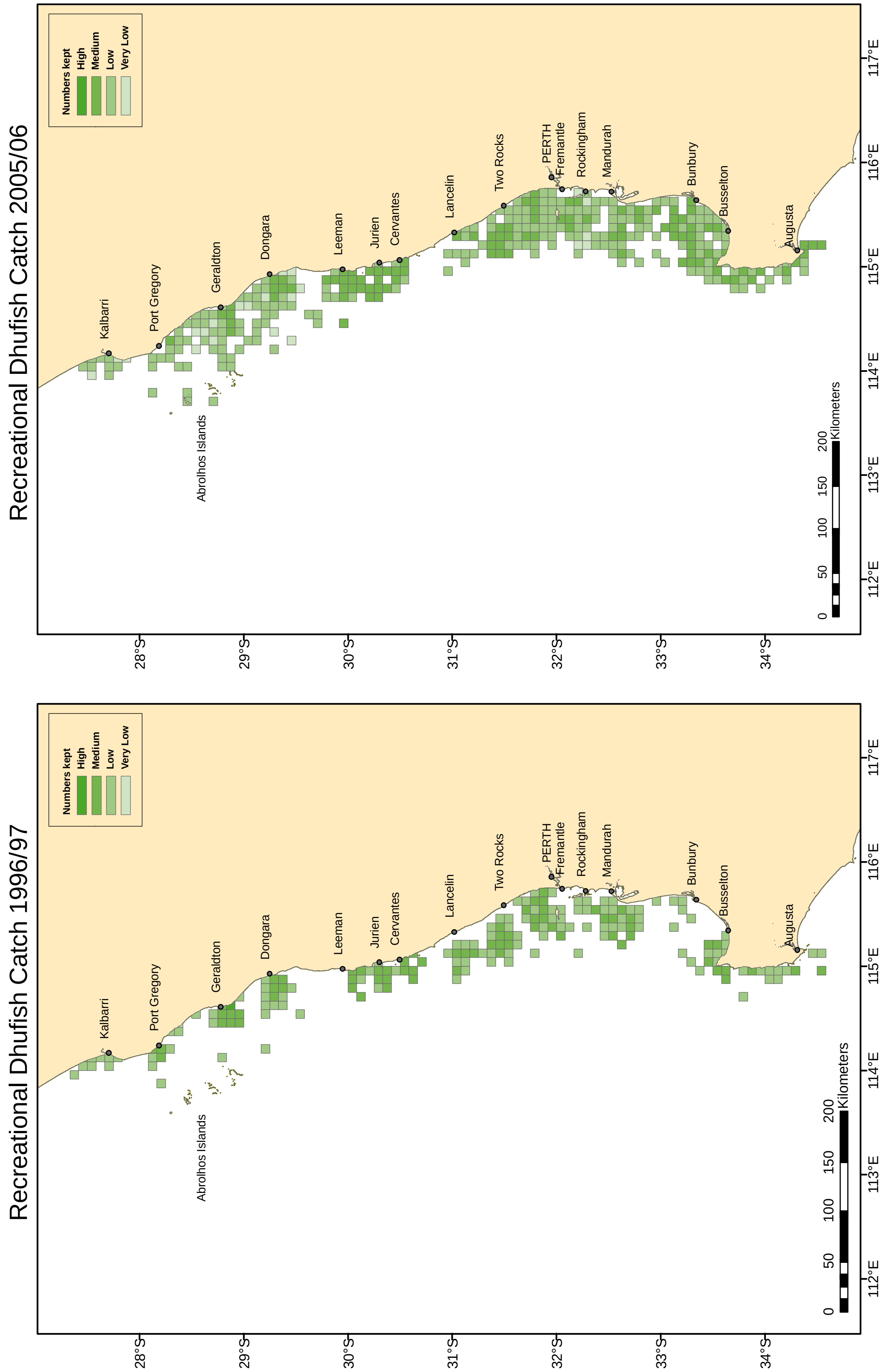


Figure 27. Estimated boat-based recreational dhufish catch using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

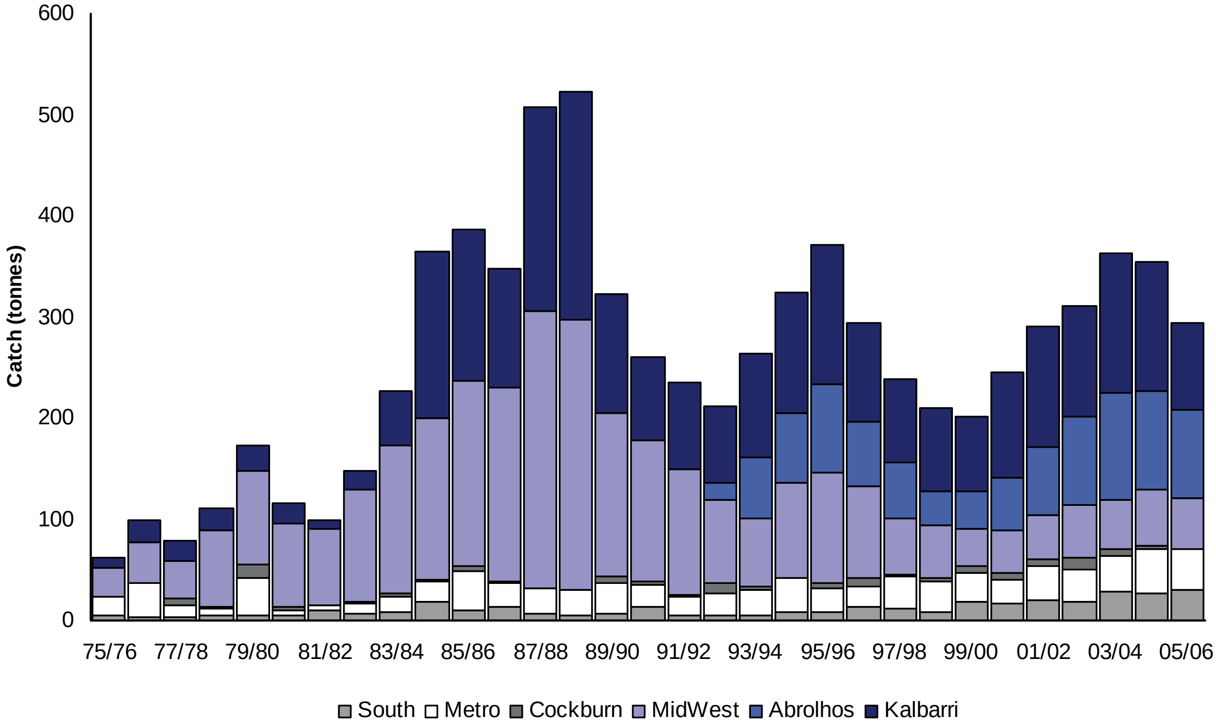


Figure 28. Commercial pink snapper catch by wetline and demersal gillnet and demersal longline fisheries in each zone. See methods for details of zones, fishery and gear descriptions.

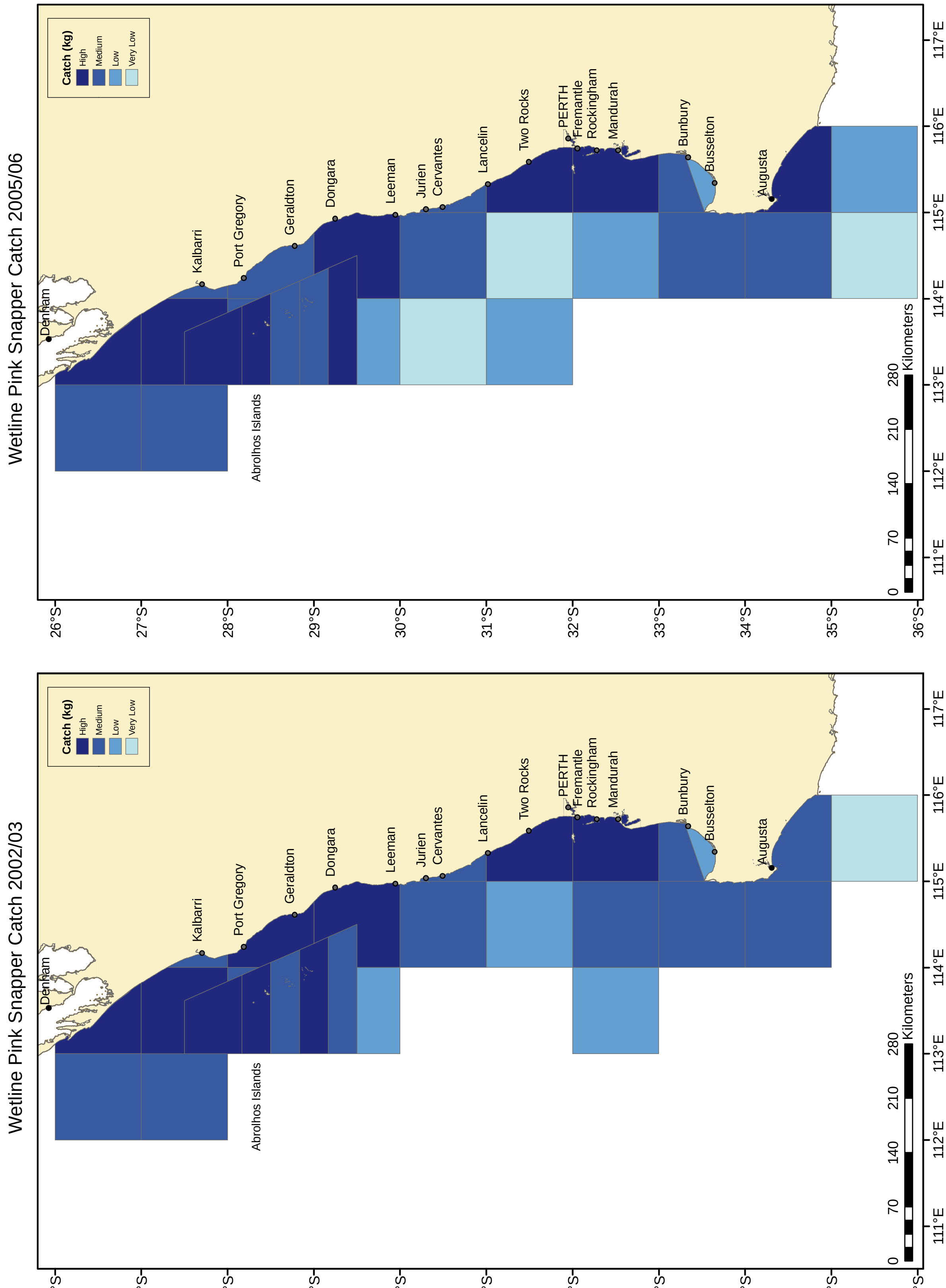


Figure 29. Commercial wetline (handline and dropline) pink snapper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions

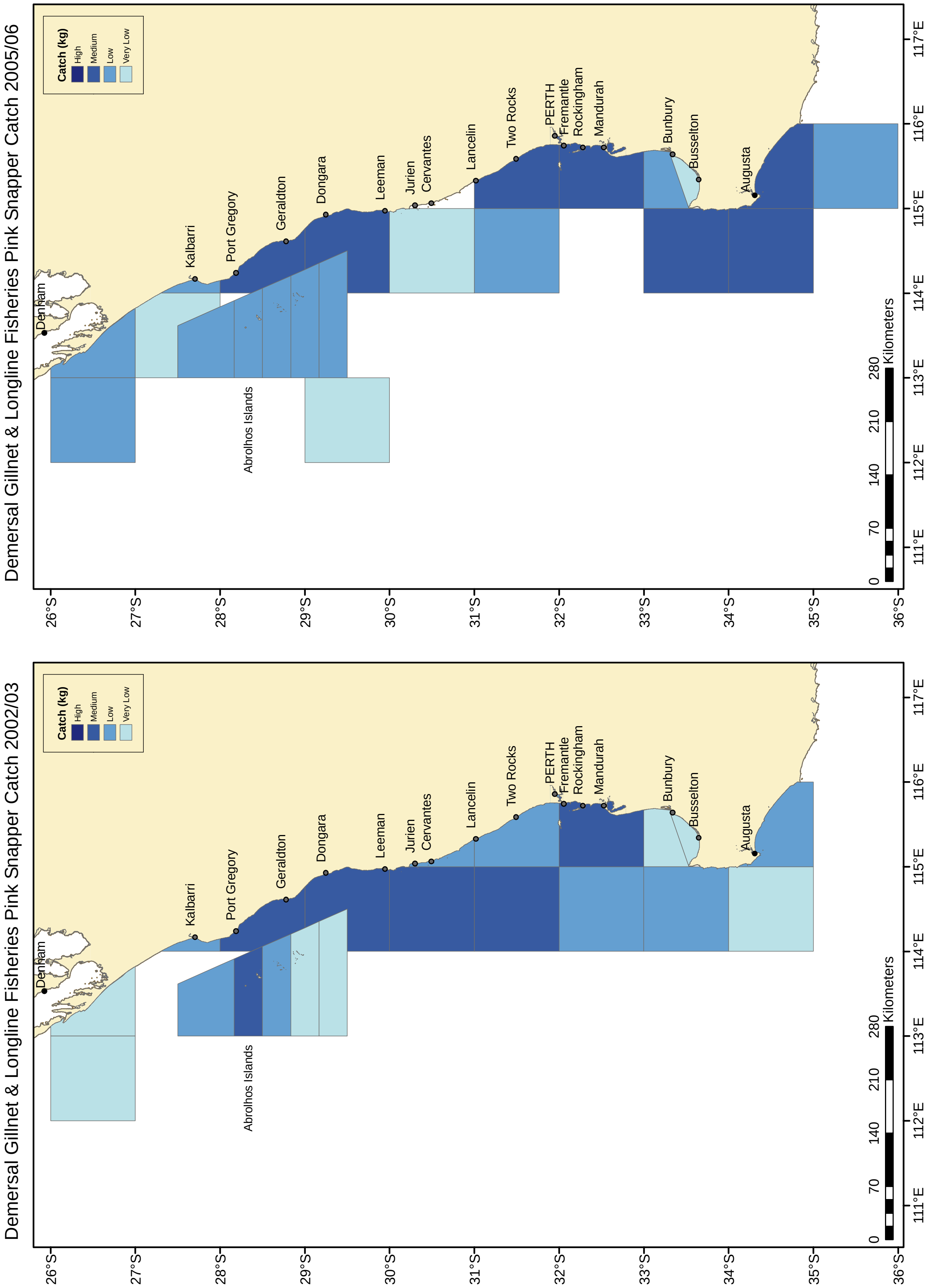


Figure 30. Commercial demersal gillnet and demersal longline fisheries pink snapper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

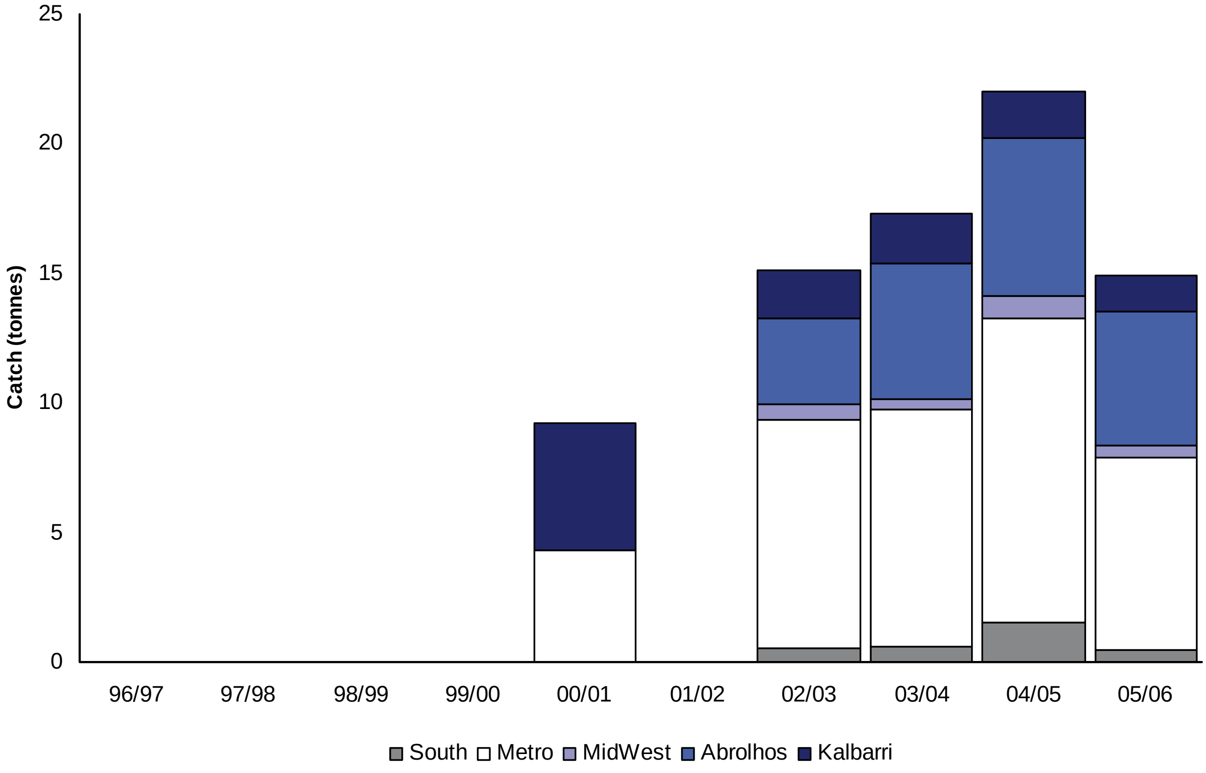


Figure 31. Tour Operators (Charter) pink snapper catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and fishery descriptions.

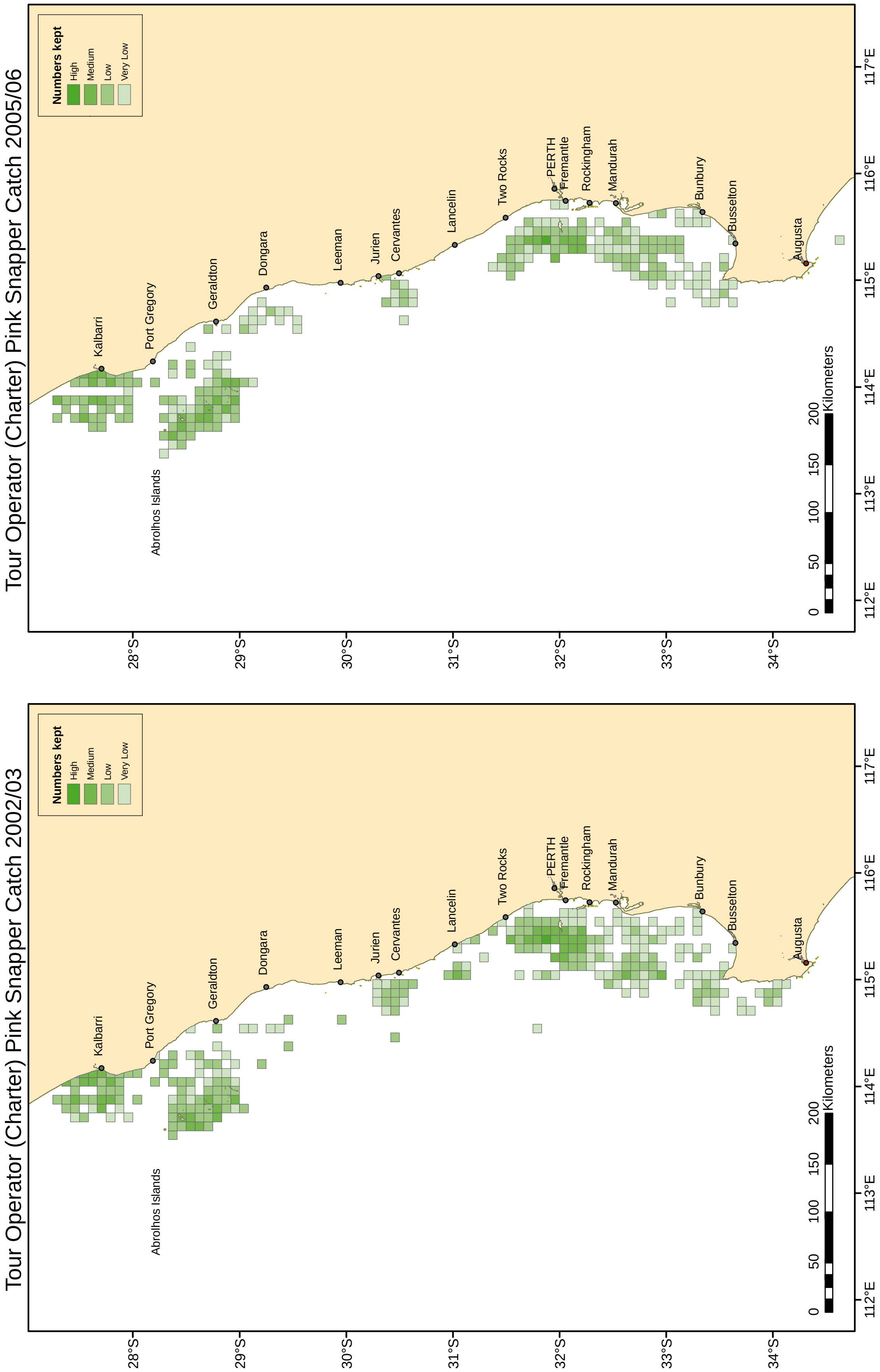


Figure 32. Tour operator (Charter) pink snapper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

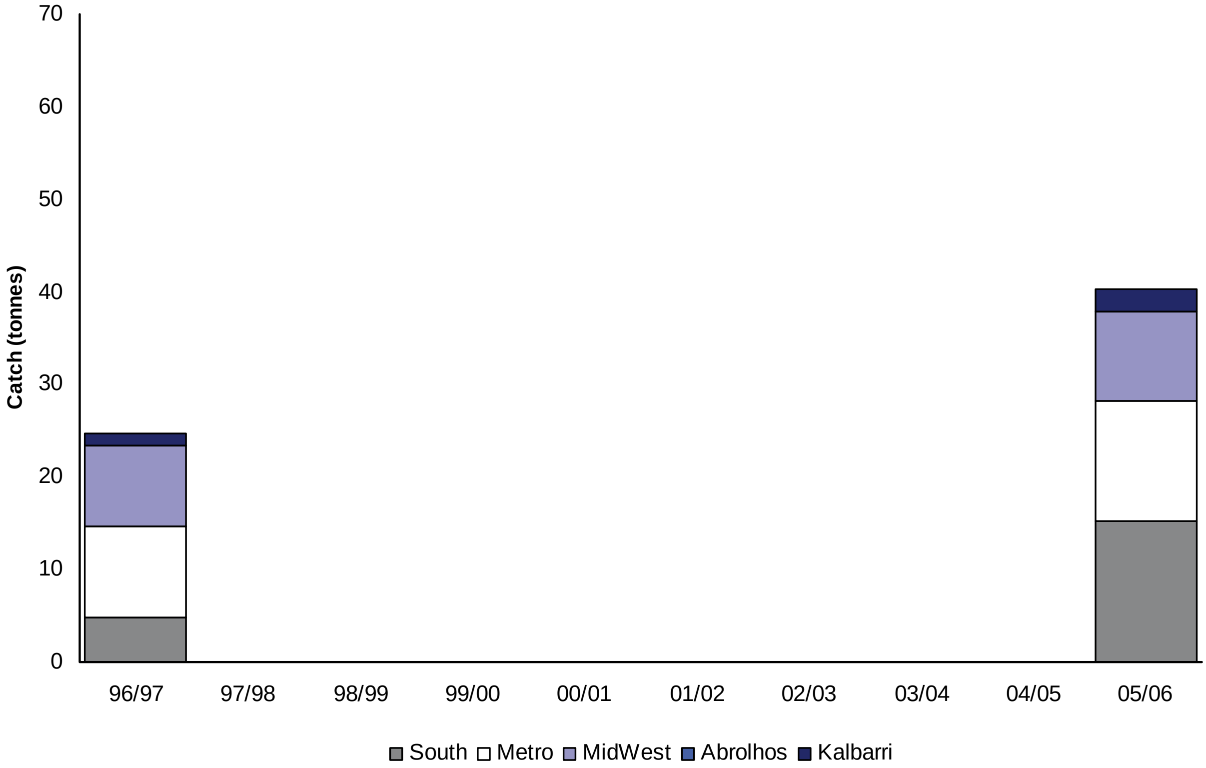


Figure 33. Estimated recreational (boat ramp creel survey) pink snapper catch in each zone. See methods for details of zones and survey descriptions.

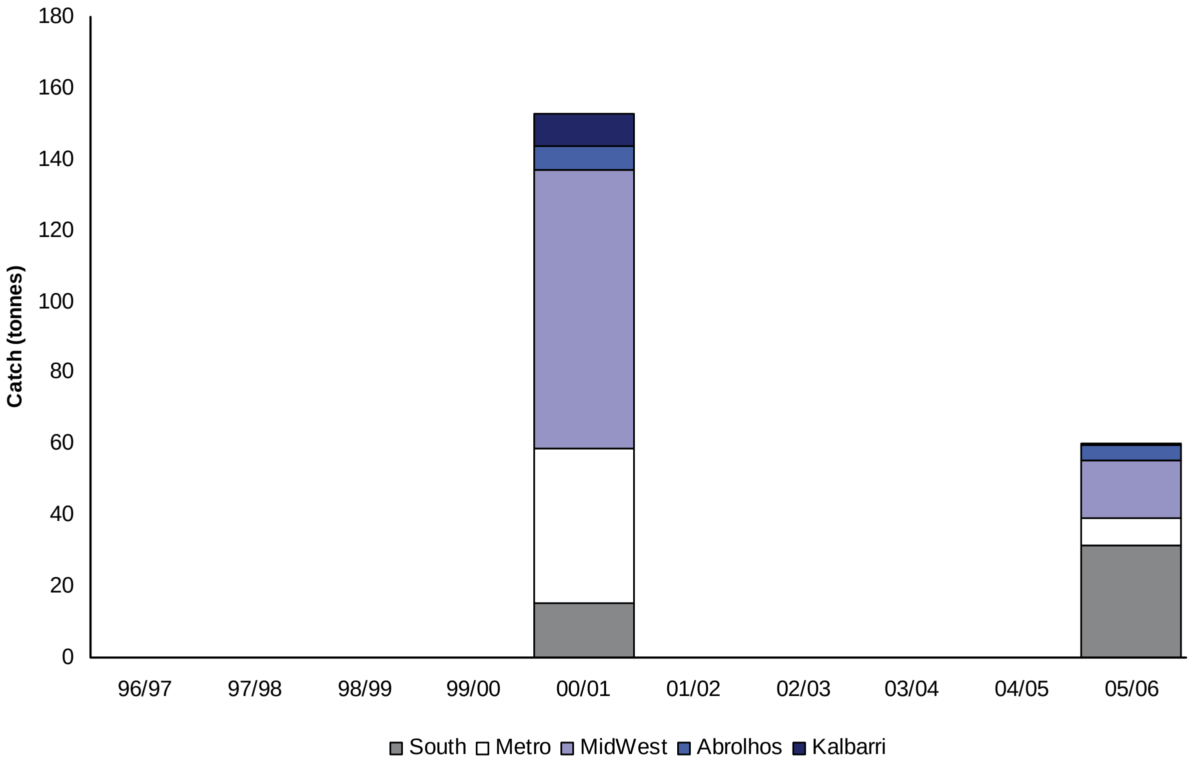


Figure 34. Estimated recreational (phone-diary survey) pink snapper catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and survey descriptions.

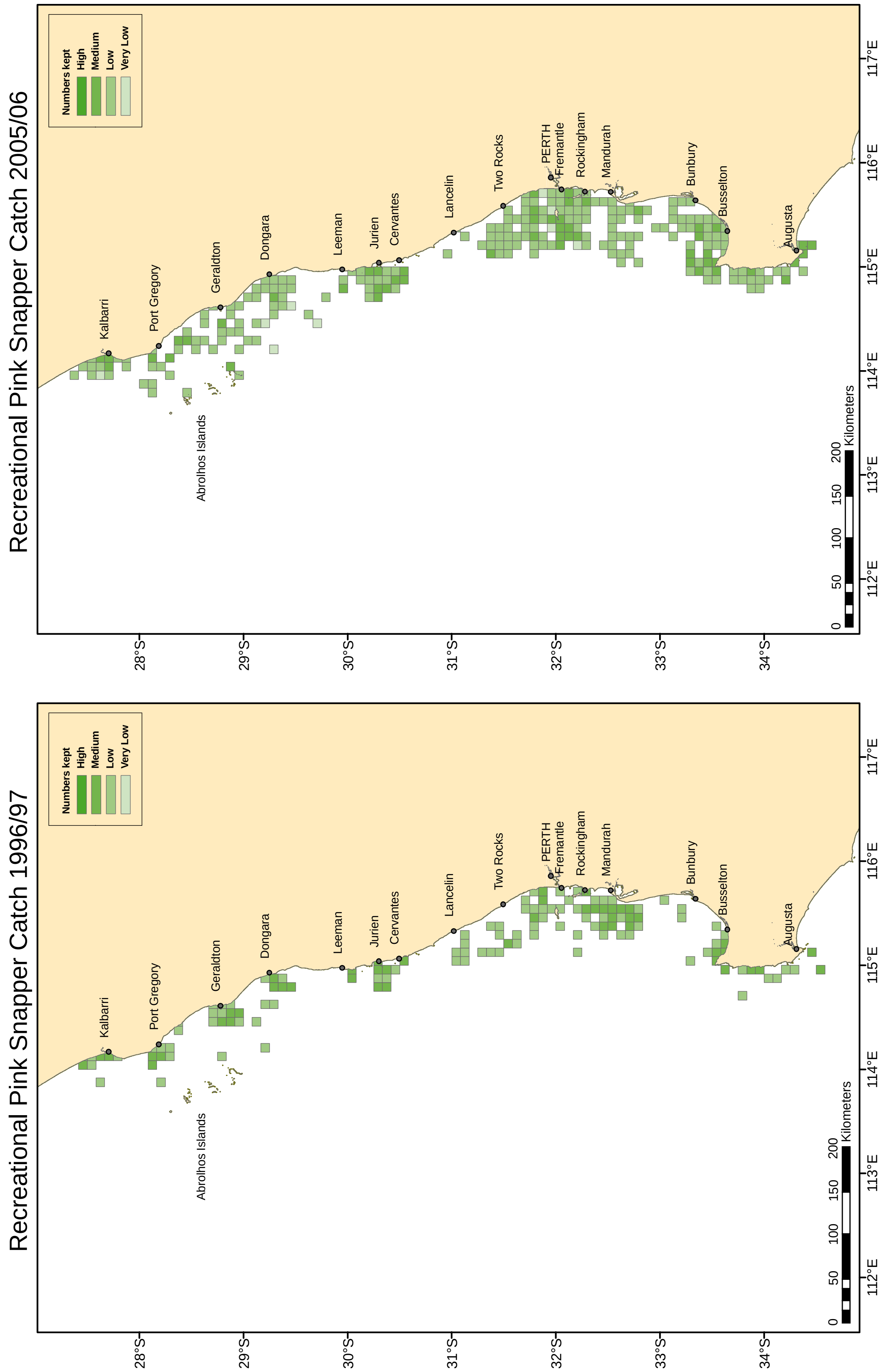


Figure 35. Estimated boat-based recreational pink snapper catch using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

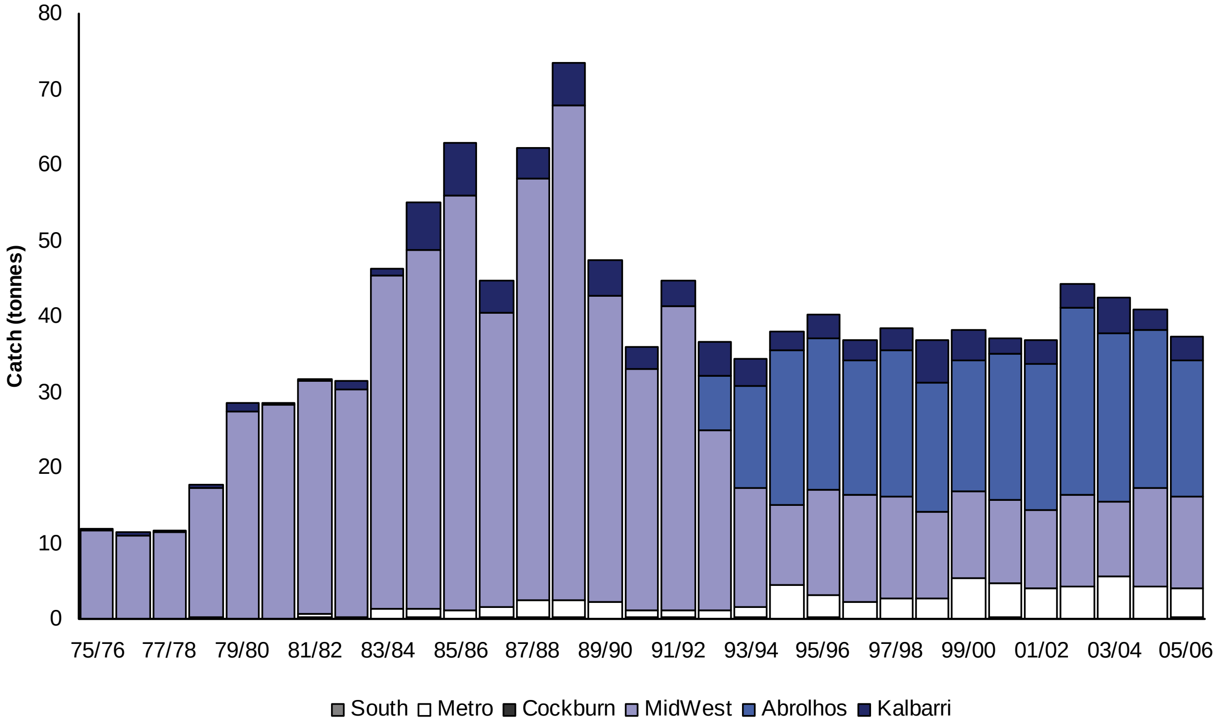


Figure 36. Commercial baldchin groper catch by wetline and demersal gillnet and demersal longline fisheries in each zone. See methods for details of zones, fishery and gear descriptions.

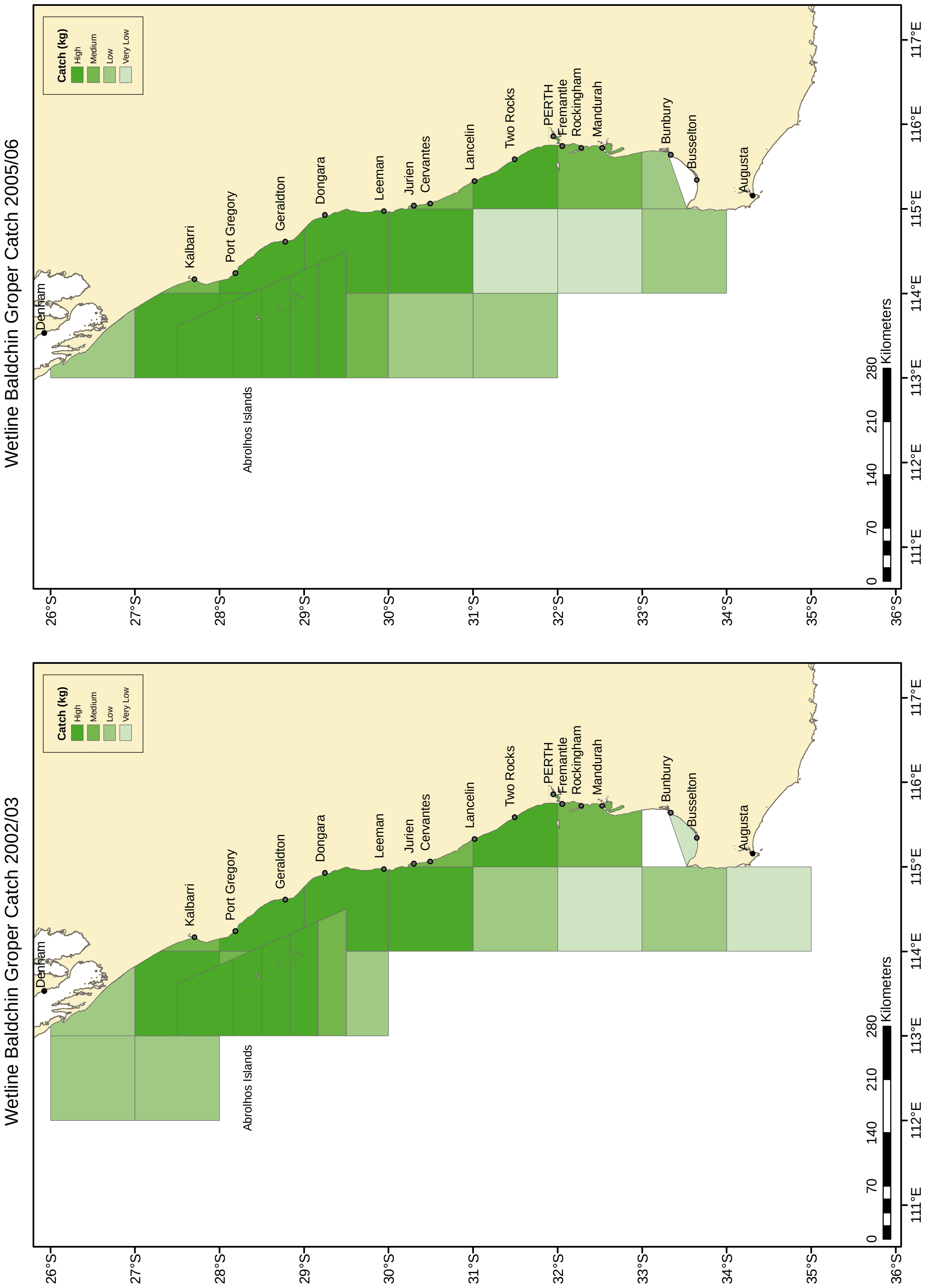


Figure 37. Commercial wetline (handline and dropline) baldchin groper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

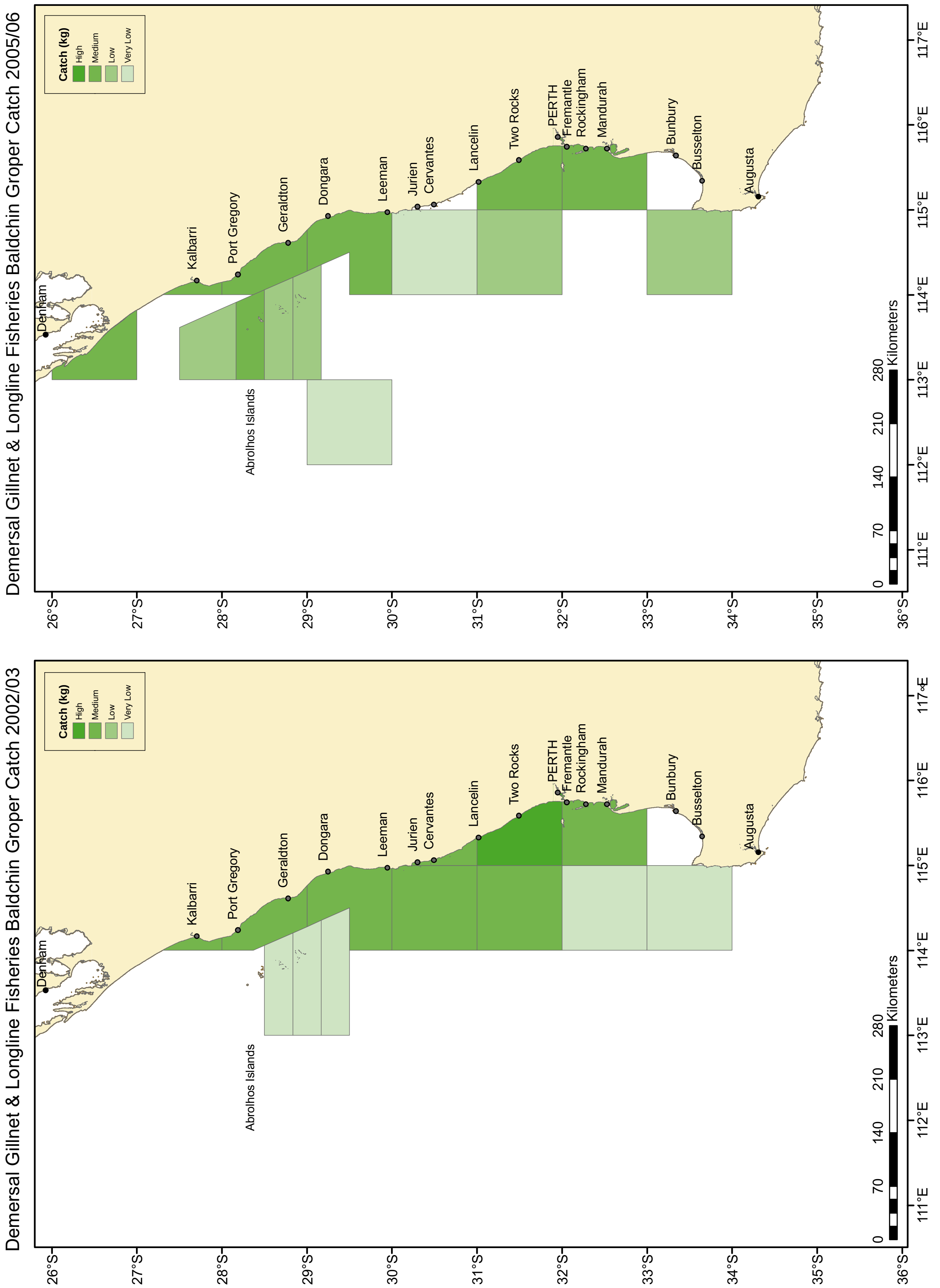


Figure 38. Commercial demersal gillnet and demersal longline fisheries baldchin groper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear description.

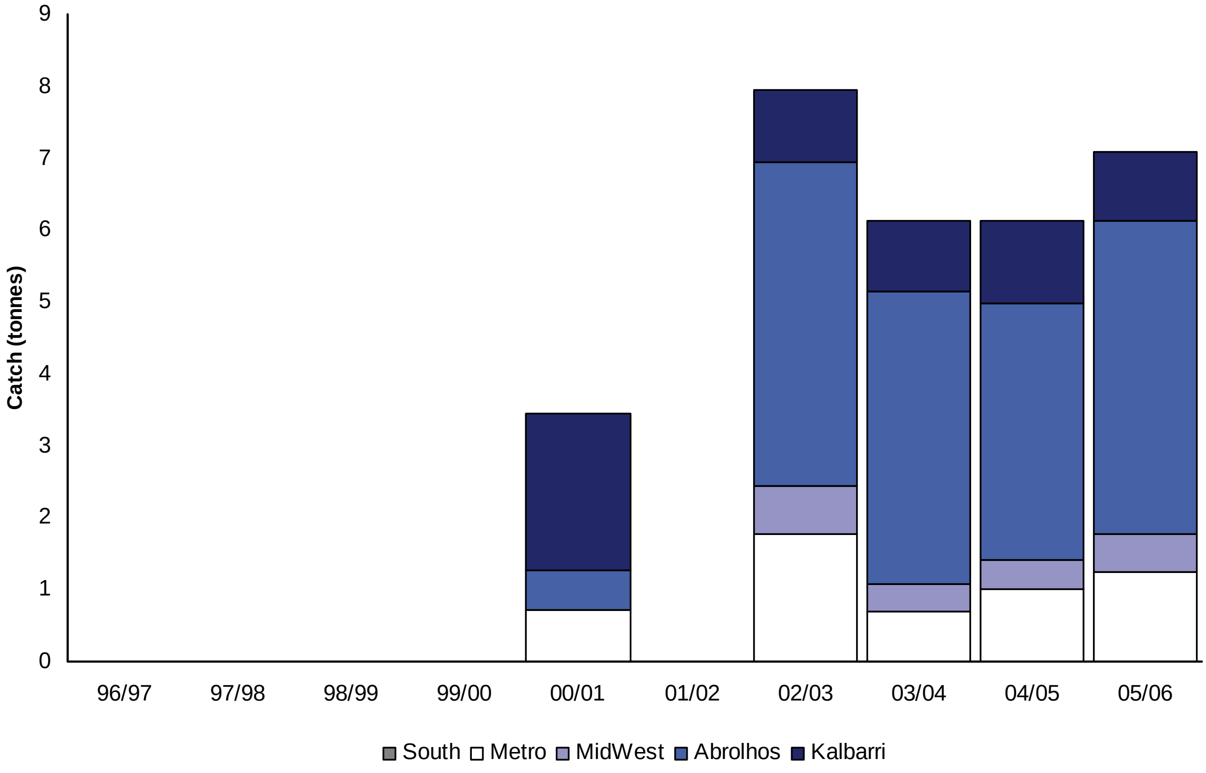


Figure 39. Tour Operators (Charter) baldchin groper catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and fishery description.

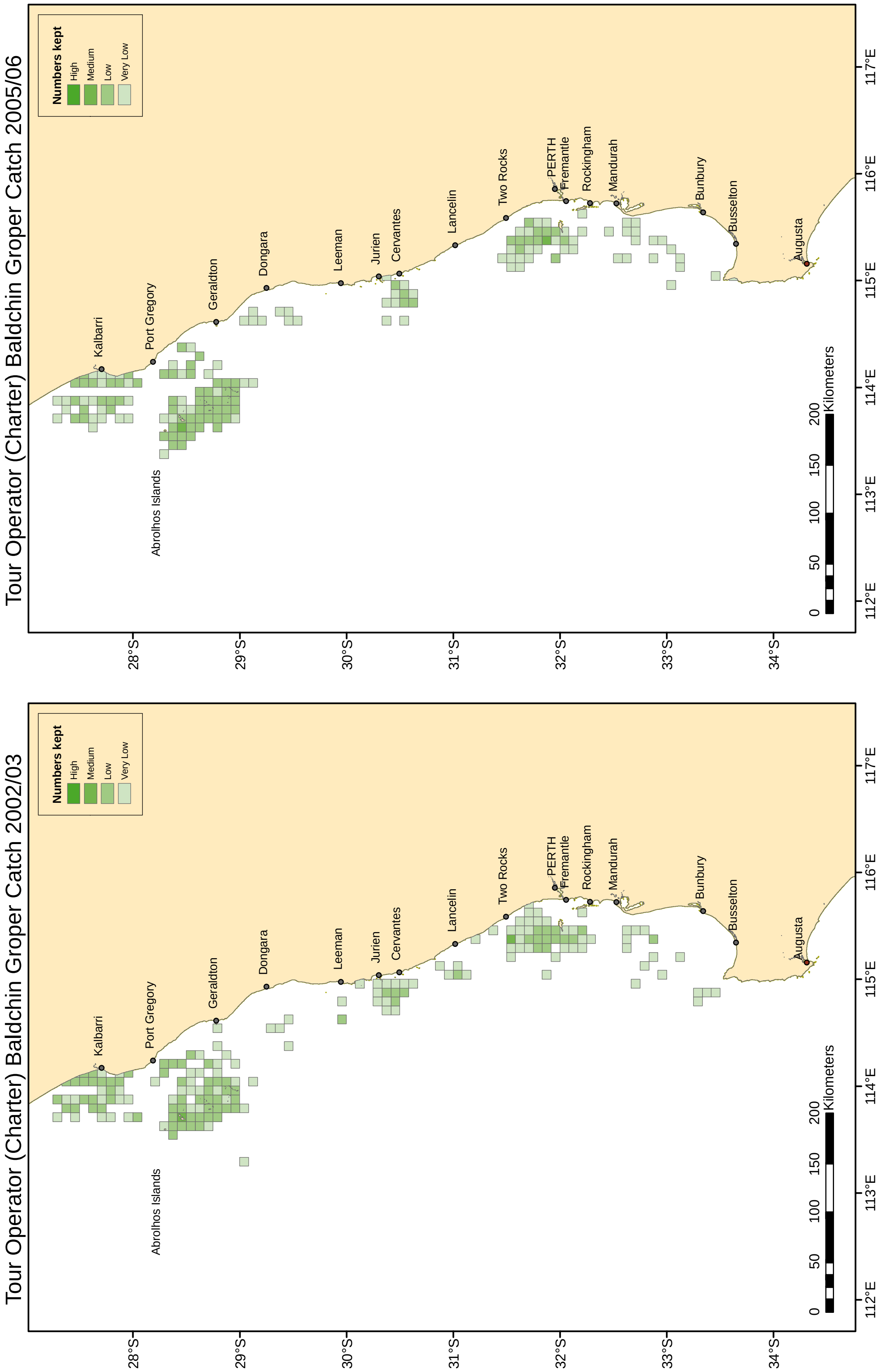


Figure 40. Tour operator (Charter) baldchin groper catch in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

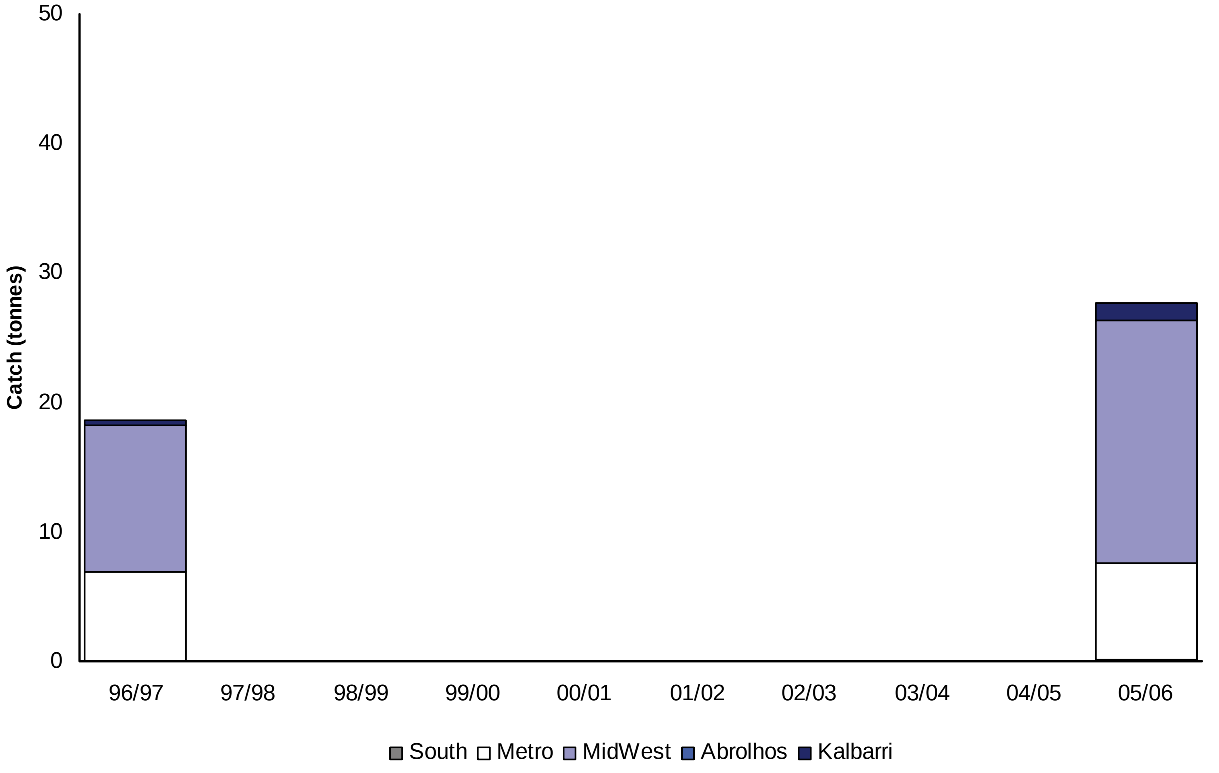


Figure 41. Estimated recreational (boat ramp creel survey) baldchin groper catch in each zone. See methods for details of zones and survey descriptions.

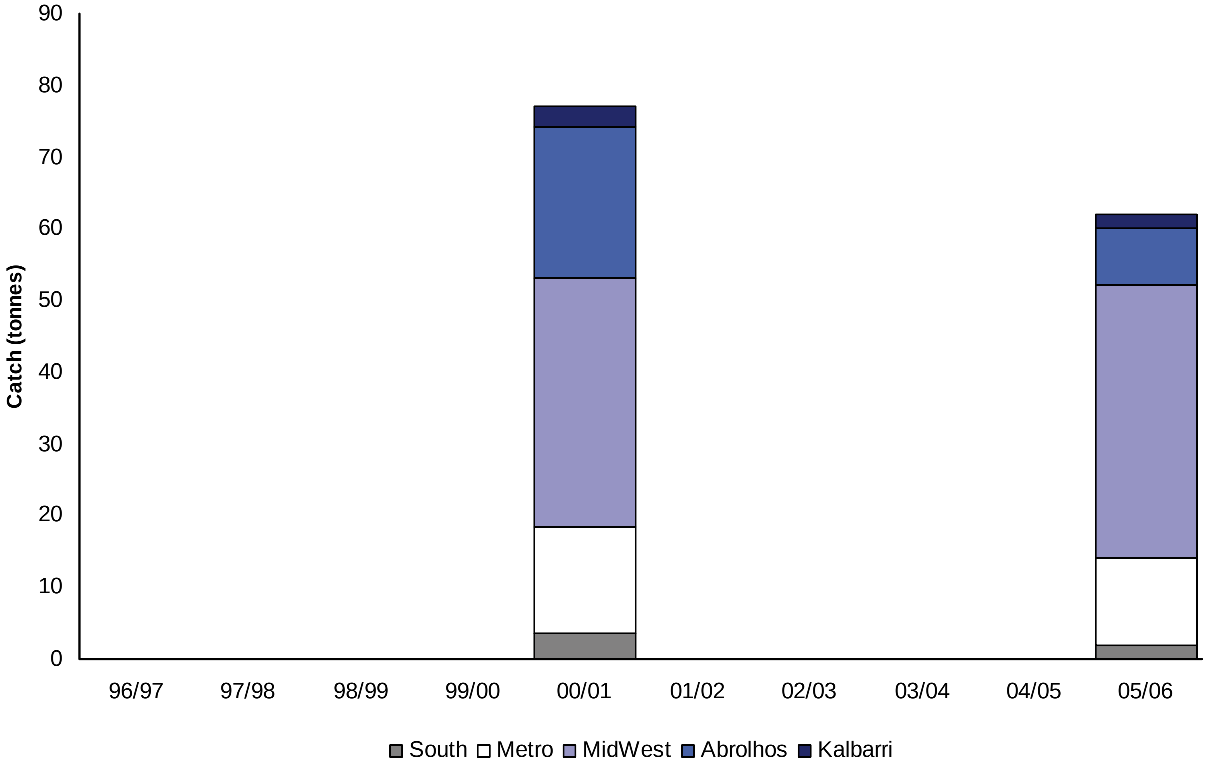


Figure 42. Estimated recreational (phone-diary survey) baldchin groper catch in each zone. The 2000/01 data is from a national phone-diary survey. See methods for details of zones and survey descriptions.

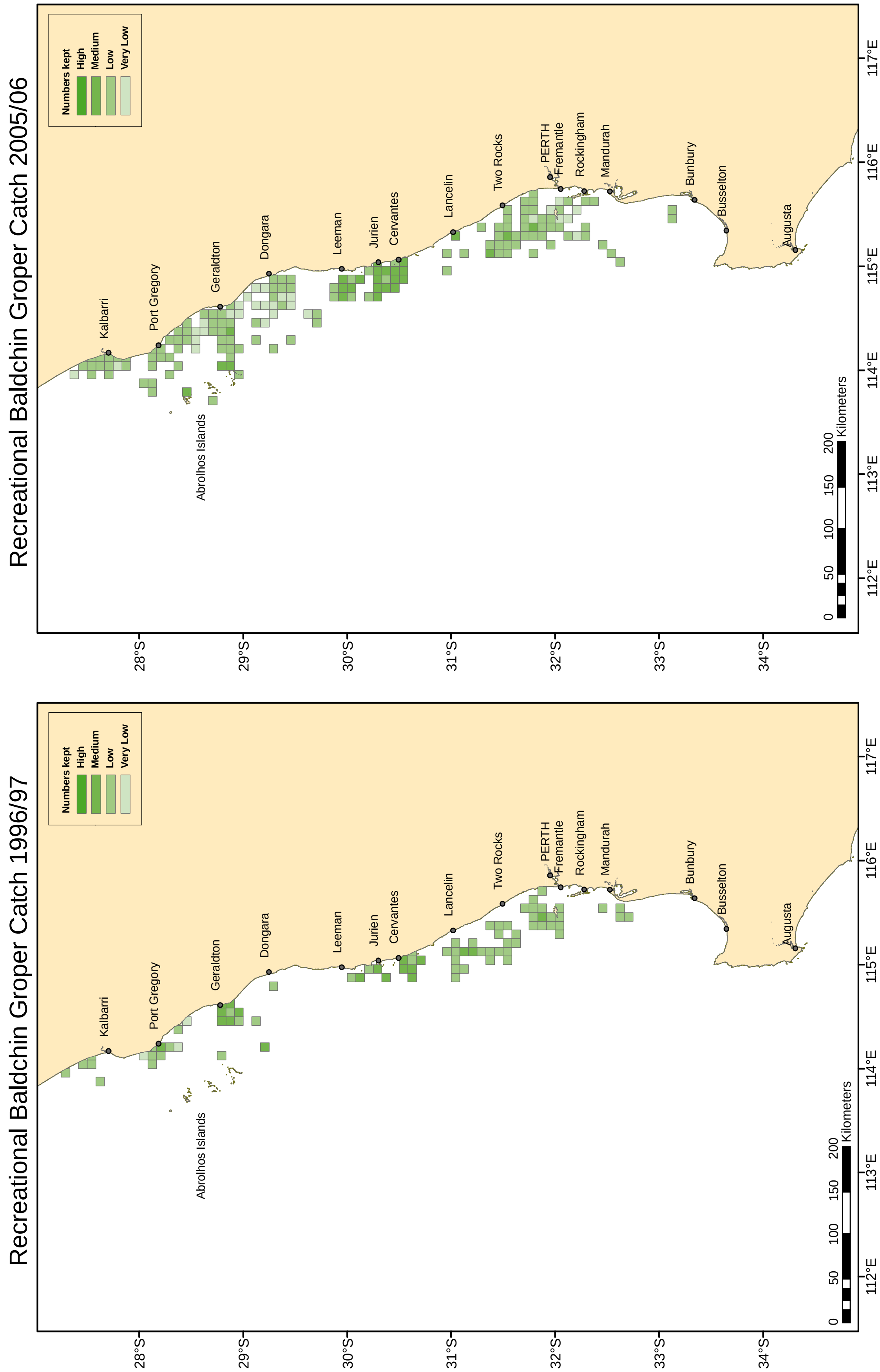


Figure 43. Estimated boat-based recreational baldchin groper catch using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey description.

4.0 Catch rate information for the indicator species

4.1 Introduction

Catch rate information for the West Coast Demersal Scalefish indicator species (dhufish, pink snapper and baldchin groper) is available from commercial and charter fishers and boat-based recreational fishers.

Catch rate data can often provide useful information on historical shifts in stock abundance providing that certain assumptions are met. Nominal or unstandardised catch rates may, however, provide a misleading indication of relative abundance if the catch rate is not proportional to abundance. If possible, effective effort should be calculated taking into account technology creep as fishers adopt new technologies; influences of environmental variables on catchability; and through observation and process errors in the calculation. Exploration of the influence of some of these factors on commercial catch and effort data was undertaken in the next section in an attempt to produced standardised catch rates.

Nominal catch rate data are presented here and trends apparent in the data are described.

4.2 Methods

4.2.1 Commercial catch and effort

Commercial fishers are required to submit compulsory catch and fishing effort logbooks since 1975 for monthly-aggregated information by fishing method used in each 1 degree block. Abrolhos blocks have been available to be used since 1992.

Time series of commercial catch rates were calculated for handline and dropline from 1975. More recently longline and gillnet have been managed under the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery since 1988 and West Coast Demersal Gillnet and Longline (Interim) Managed Fishery since 1998. Consequently time series of catch rates were calculated by gillnet gears. The time series of longline data is limited to only a few years and hence catch rates were not presented. Linear regression was used to determine if the observed trend was statistically significant (*i.e.* $P<0.05$).

Spatial commercial wetline (handline and dropline) and demersal gillnet and demersal longline catch rates were calculated and presented for each block for 2002/03 and 2005/06 for comparison with charter catch rates.

4.2.2 Charter catch and effort

Spatial charter catch rates were calculated from compulsory tour operator daily logbooks for 2002/03 and 2005/06. Tour operators are required to submit compulsory daily catch and fishing effort logbook data by 5x5 nautical mile blocks.

4.2.3 Recreational catch and effort

Spatial estimates of recreational catch rates by 5x5 nautical mile blocks were calculated from west coast boat ramp creel surveys carried out in 1996/97 and 2005/06. The methods for these surveys have now been developed and tested (Sumner and Williamson 1999). Catch rates were calculated assuming that demersal fishing is carried out by ocean line fishing, consequently fishing trips in estuaries and fishing gears including pots and traps were omitted from the analyses.

To ensure data confidentiality, information on the maps were presented as high, medium, low and very low based on logarithmic scales as shown below. The different colour schemes have been used so that data can be presented on different scales as appropriate (i.e. 0 – 10, 0 – 100 and 0 – 1000)

0.1 – 1	10 – 100	100 – 1000
0.01 – 0.1	1 – 10	10 – 100
0.001 – 0.01	0.1 – 1	1 – 10
0 – 0.001	0 – 0.1	0 – 1

A nil category was used to represent where effort was present in a block but there was no corresponding catch.

4.3 Results and discussion

4.3.1 Dhufish catch rates

Wetline catch rates of dhufish have been variable between 1975/65 and 2005/06 with Kalbarri and Abrolhos zones indicating an increase, Midwest and Metro remaining steady and the South zone suggesting a slight decline over that period (Figure 44). Conversely, gillnet catch rates show large consistent increases during this period for the South, Metro and Midwest zones (Figure 45). There was limited gillnet data for Kalbarri and Abrolhos zones and hence catch rates were not calculated for these zones.

Distributions of dhufish catch rates (Figures 46-49) show relatively consistent spatial coverage unlike the variable spatial pattern of dhufish catches. Spatial distribution of dhufish catch rates increased markedly for boat-based recreational fishing between 1996/97 and 2005/06, increased slightly for wetline, demersal gillnet and demersal longline, and charter fishing in the northern regions, but decreased for charter fishing in southern regions 2002/03 and 2005/06 (Figures 46-49).

While the nominal catch rates provide some insight regarding the temporal and spatial distribution of dhufish, they can provide a misleading indication of relative abundance especially due to increases in the effective effort through the adoption of new technologies. The influence of some of these factors on dhufish, pink snapper and baldchin groper catch rates is explored in the next section.

4.3.2 Pink snapper catch rates

Wetline catch rates of pink snapper have been highly variable between 1975/65 and 2005/06 with Kalbarri and South zones indicating an increase while the Midwest, Abrolhos and Metro zones remained steady over that period (Figure 50). Conversely gillnet catch rates show large increases during this period for the South, Metro and Midwest zones (Figure 51). There was limited gillnet data for Kalbarri and Abrolhos zones and hence catch rates were not calculated for these zones.

The spatial distributions of pink snapper catch rates increased markedly for boat-based recreational fishing between 1996/97 and 2005/06, increased slightly for wetline, demersal gillnet and demersal longline and charter fishing in the northern regions, however decreased for charter fishing in southern regions between 2002/03 and 2005/06 (Figures 52-55).

4.3.3 Baldchin groper catch rates

Wetline catch rates of baldchin groper have been highly variable between 1975/65 and 2005/06 with Midwest and Abrolhos zones indicating a decline while the Kalbarri, Metro and South zones remained steady over that period (Figure 56). Conversely, gillnet catch rates show large consistent increases during this period for the Metro and Midwest zones while catch rates remain steady in the South zone (Figure 57). There was limited gillnet data for Kalbarri and Abrolhos zones and hence catch rates were not calculated for these zones.

The distribution of baldchin groper catch rates show relatively consistent spatial coverage unlike the variable spatial pattern of baldchin groper catches (Figures 58-61). Distributions of baldchin groper catch rates show increases in spatial pattern in the northern regions and relatively consistent spatial coverage in the southern regions for all fishing sectors between the two representative years (Figures 58-61).

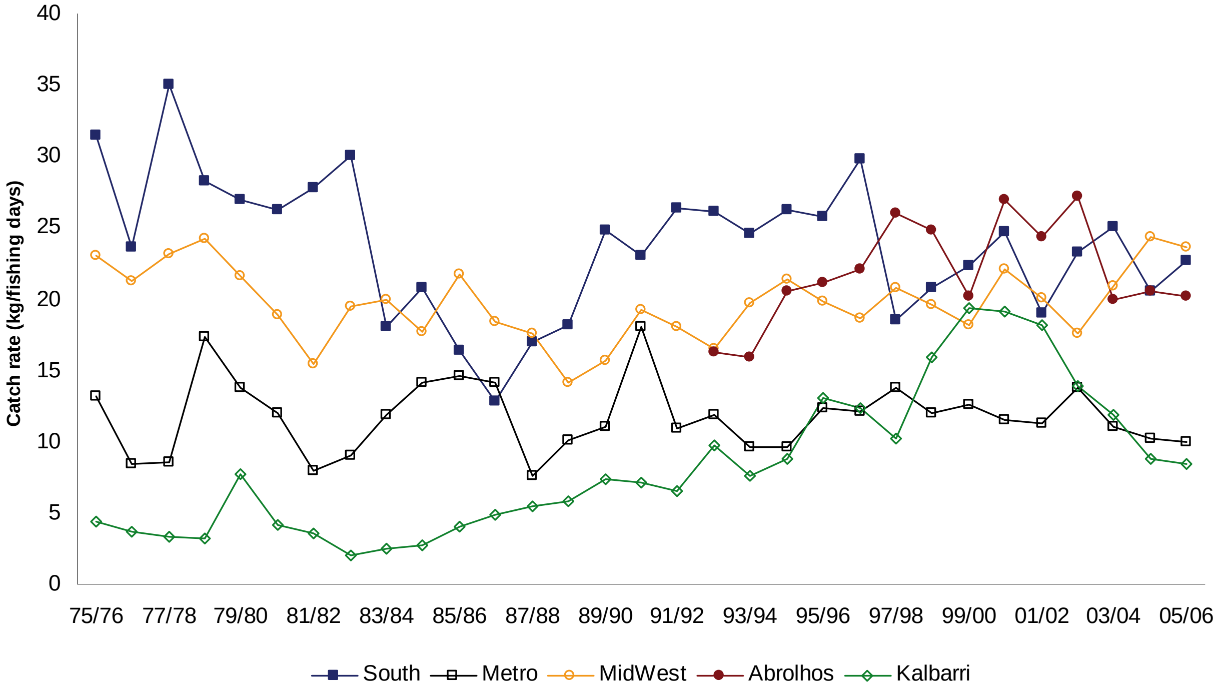


Figure 44. Commercial handline and dropline dhufish catch rates by zone. See methods for details of zones, fishery and gear descriptions.

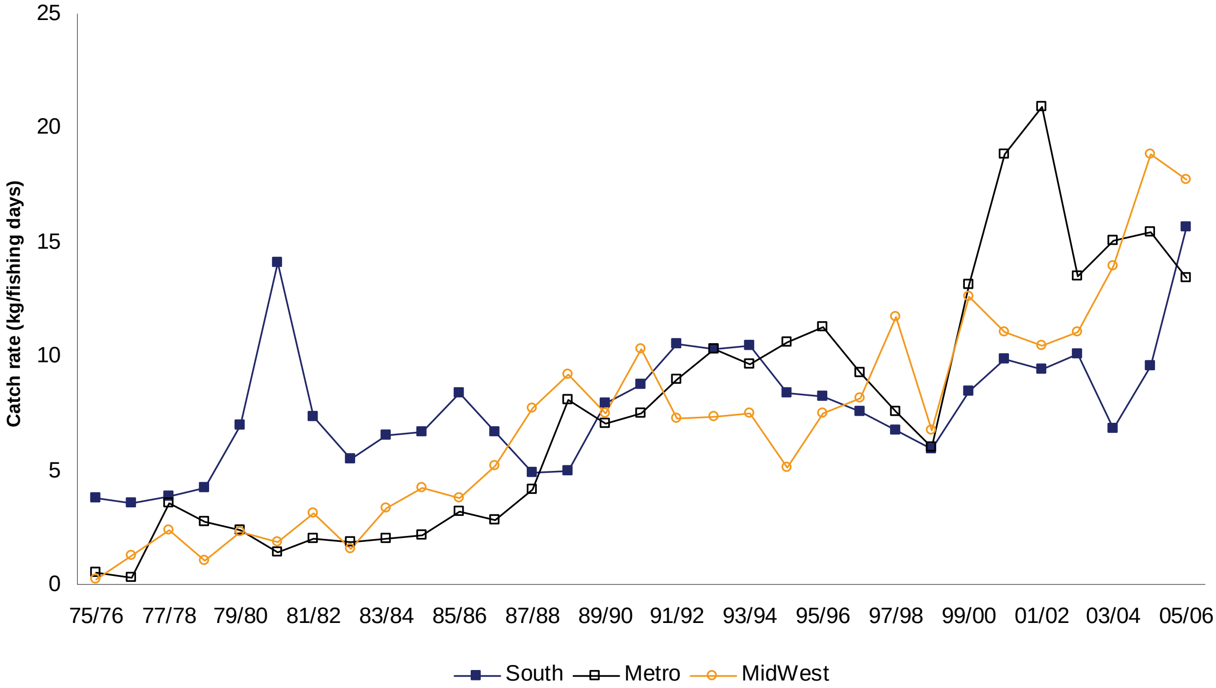
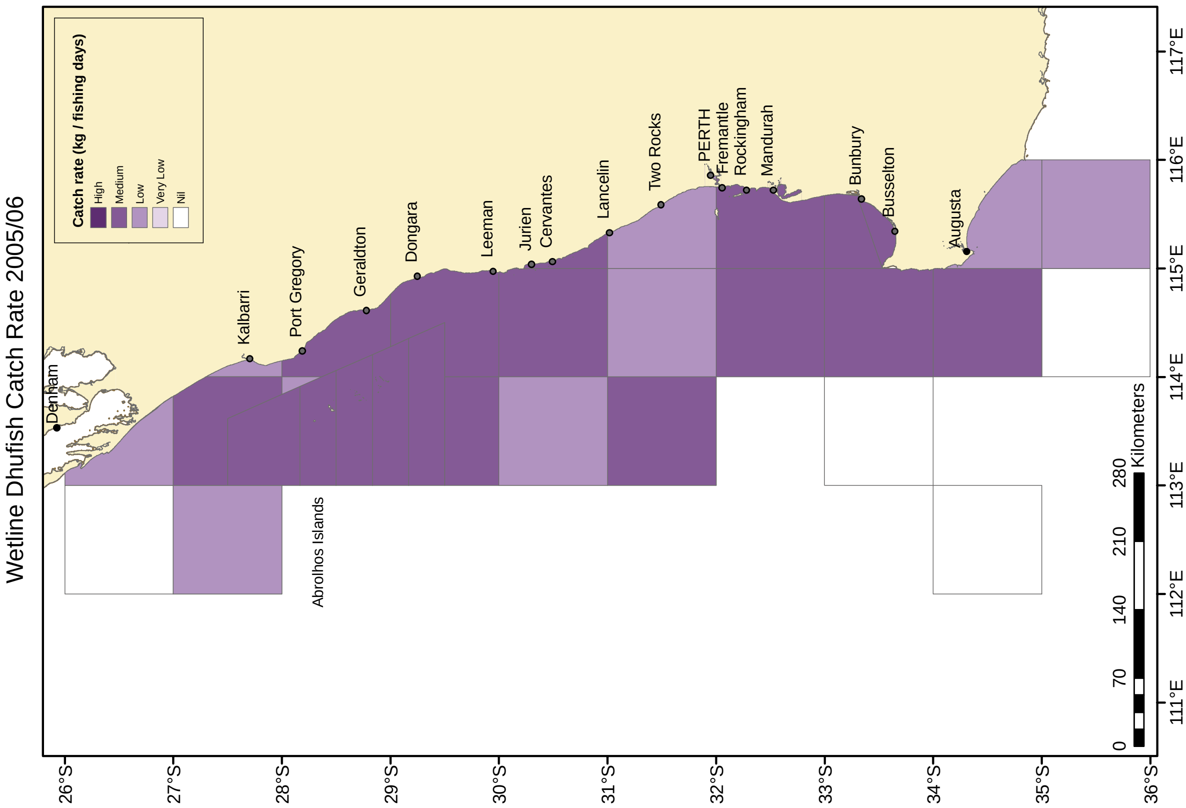


Figure 45. Commercial gillnet dhufish catch rates by zone. See methods for details of zones, fishery and gear descriptions.



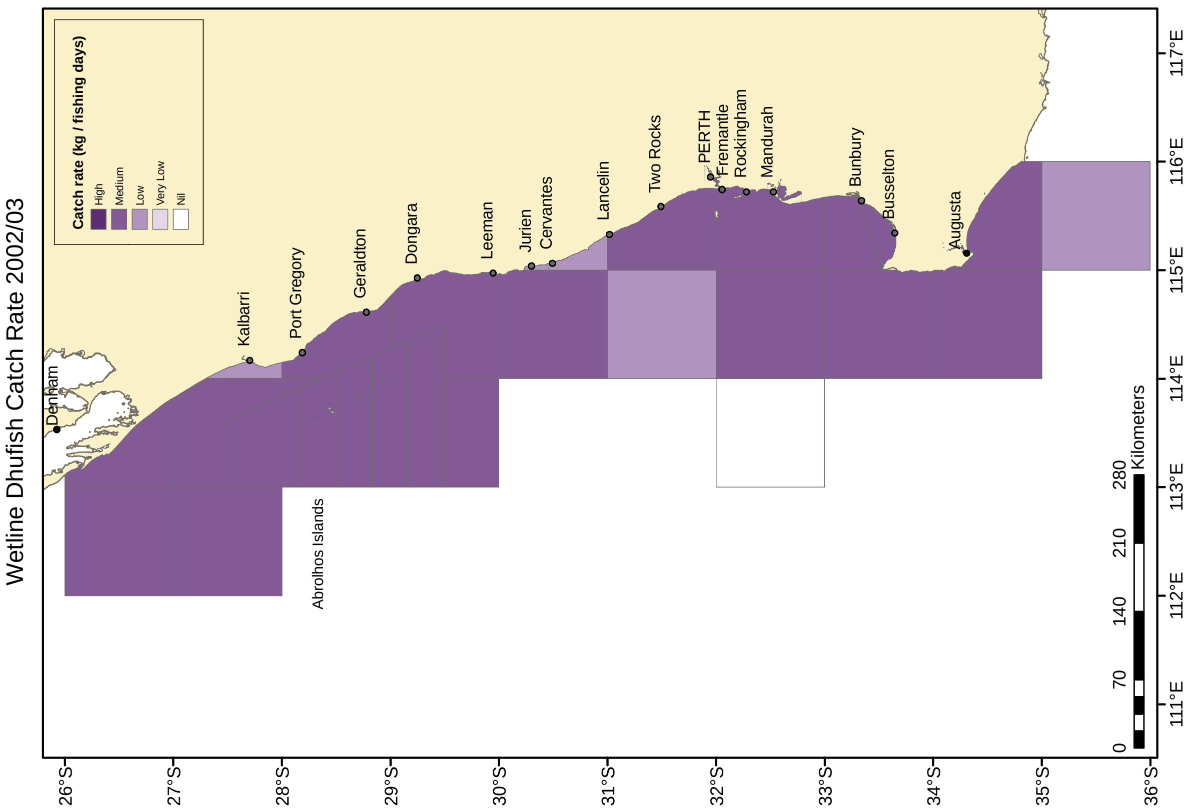
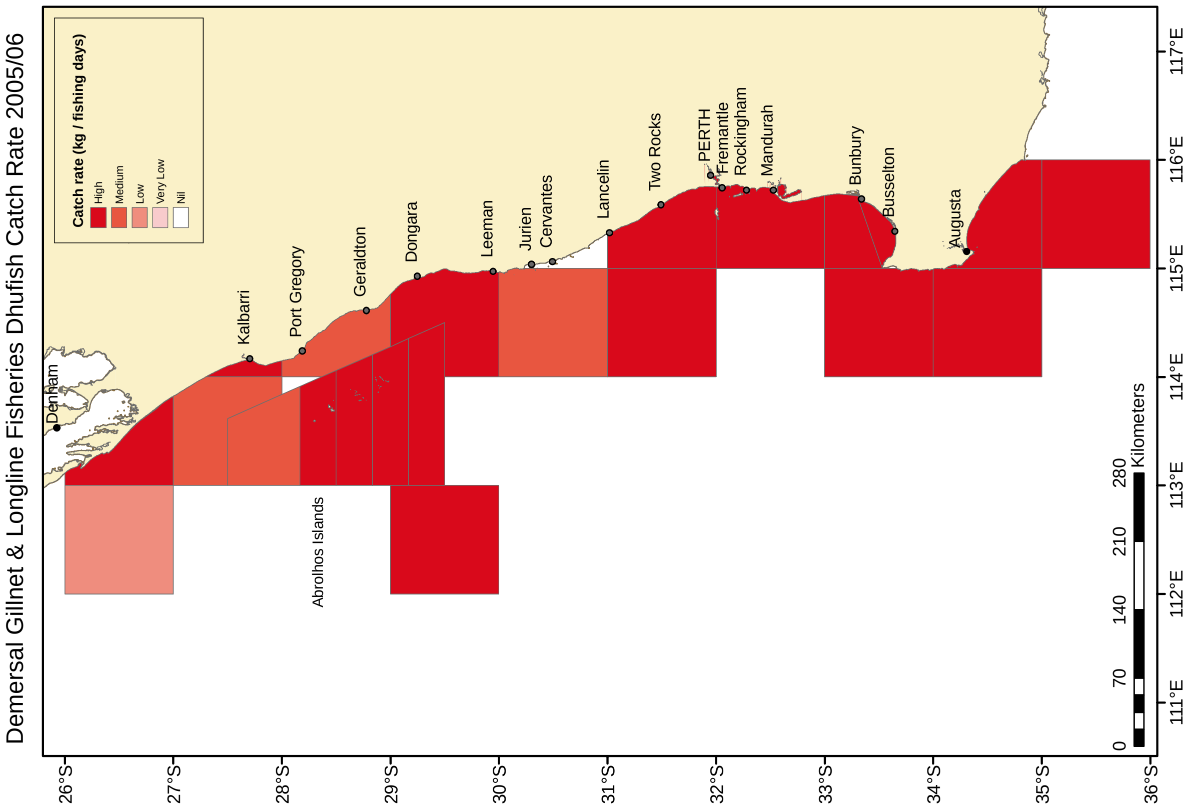


Figure 46. Commercial wetline (handline and dropline) dhufish catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.



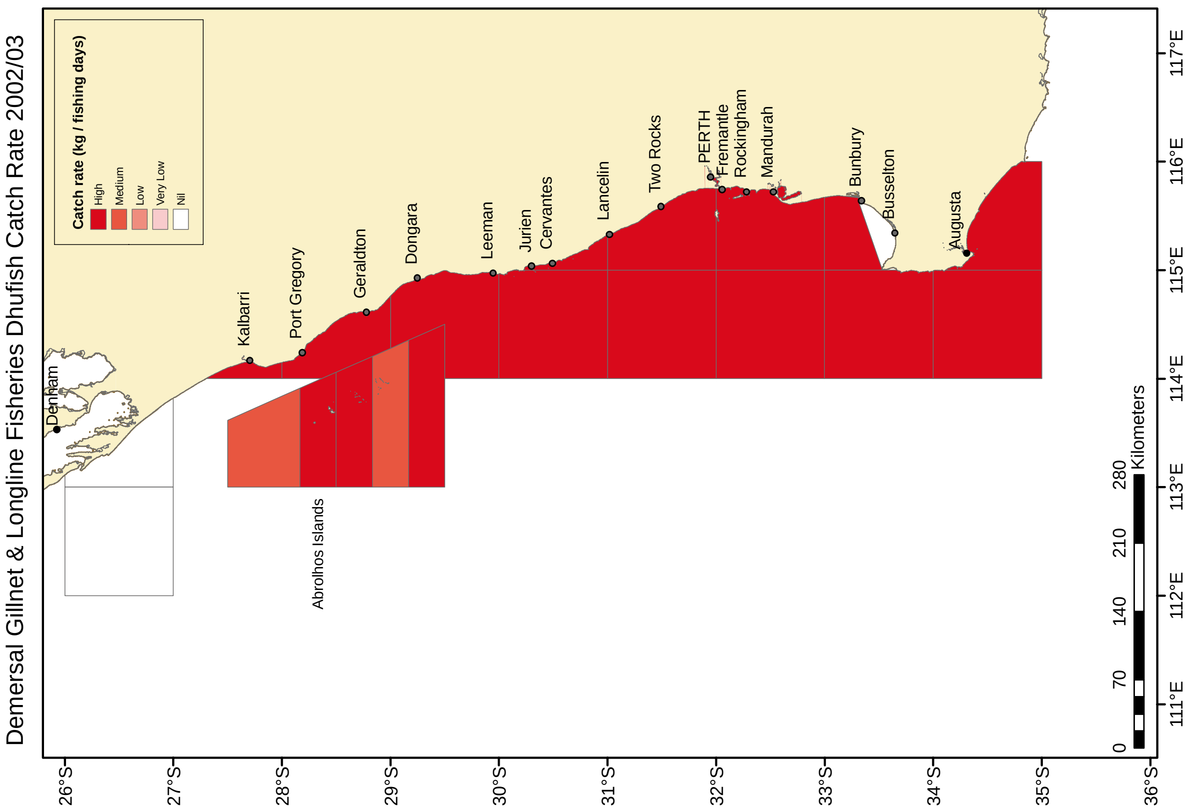
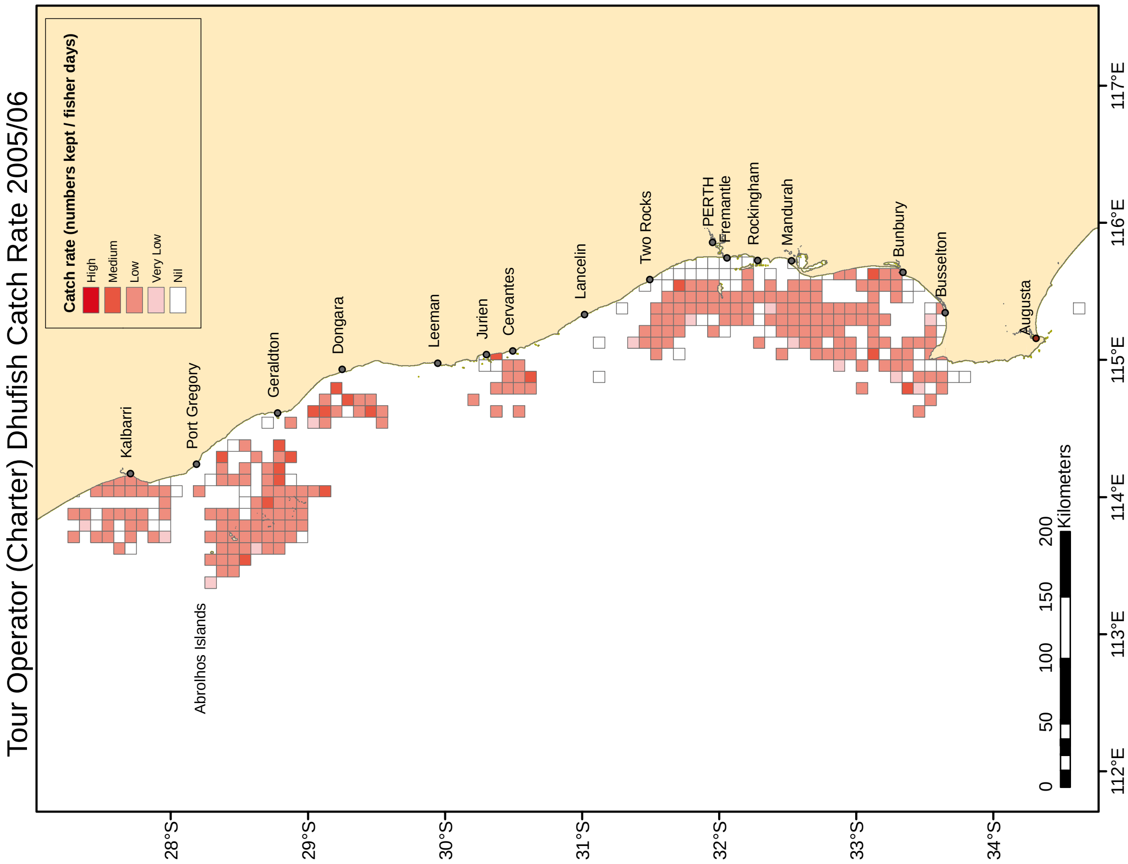


Figure 47. Commercial demersal gillnet and demersal longline fisheries dhufish catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.



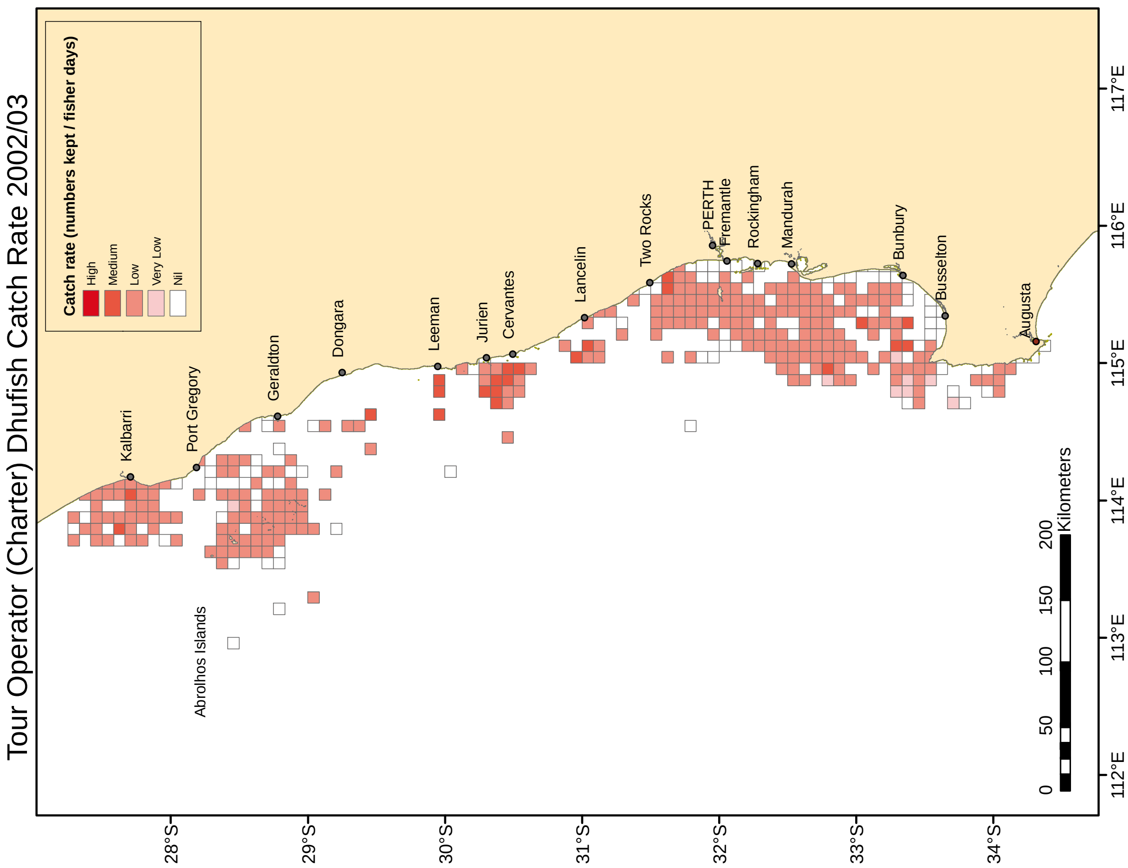


Figure 48. Tour operator (Charter) dhufish catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

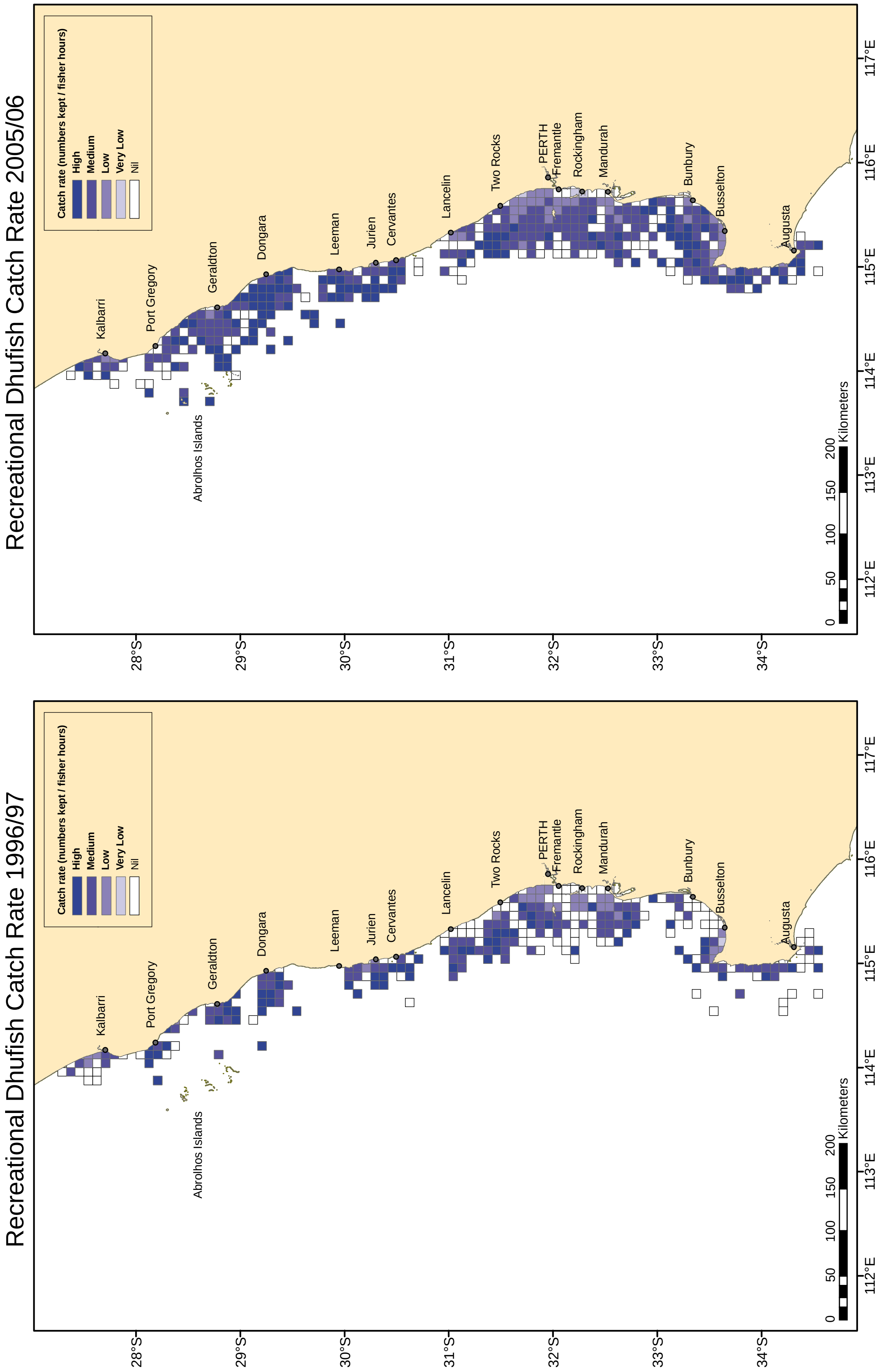


Figure 49. Estimated boat-based recreational dhufish catch rates using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

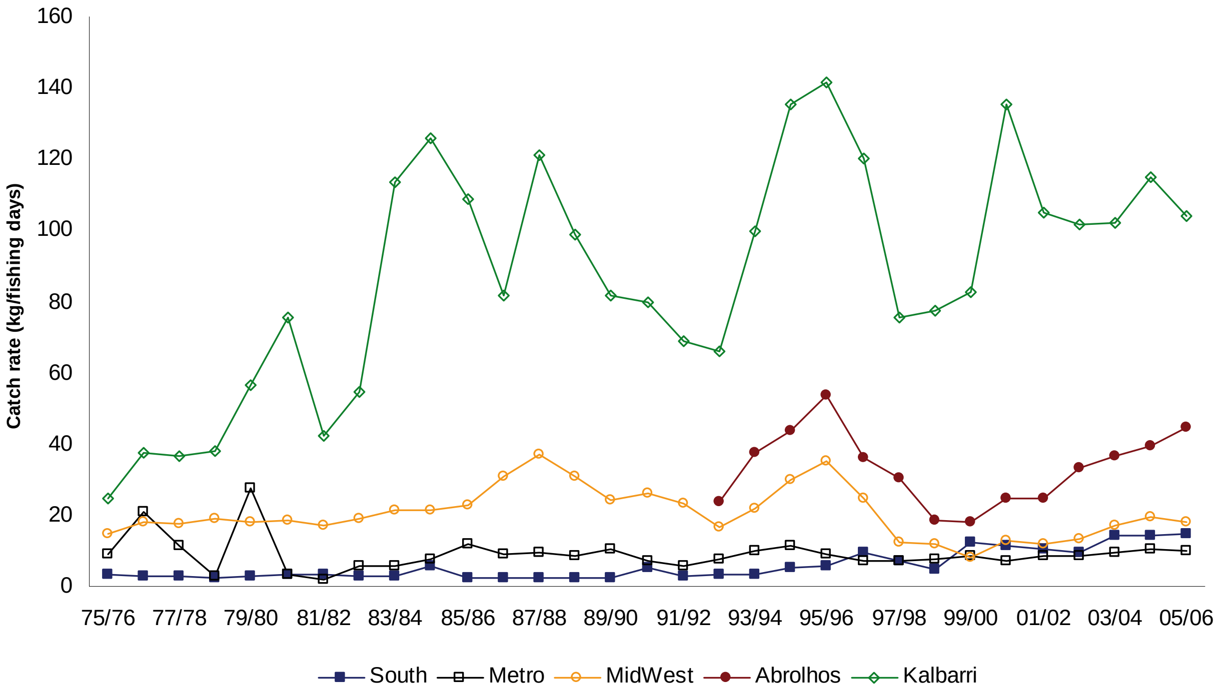


Figure 50. Commercial handline and dropline pink snapper catch rates by zone. See methods for details of zones, fishery and gear descriptions.

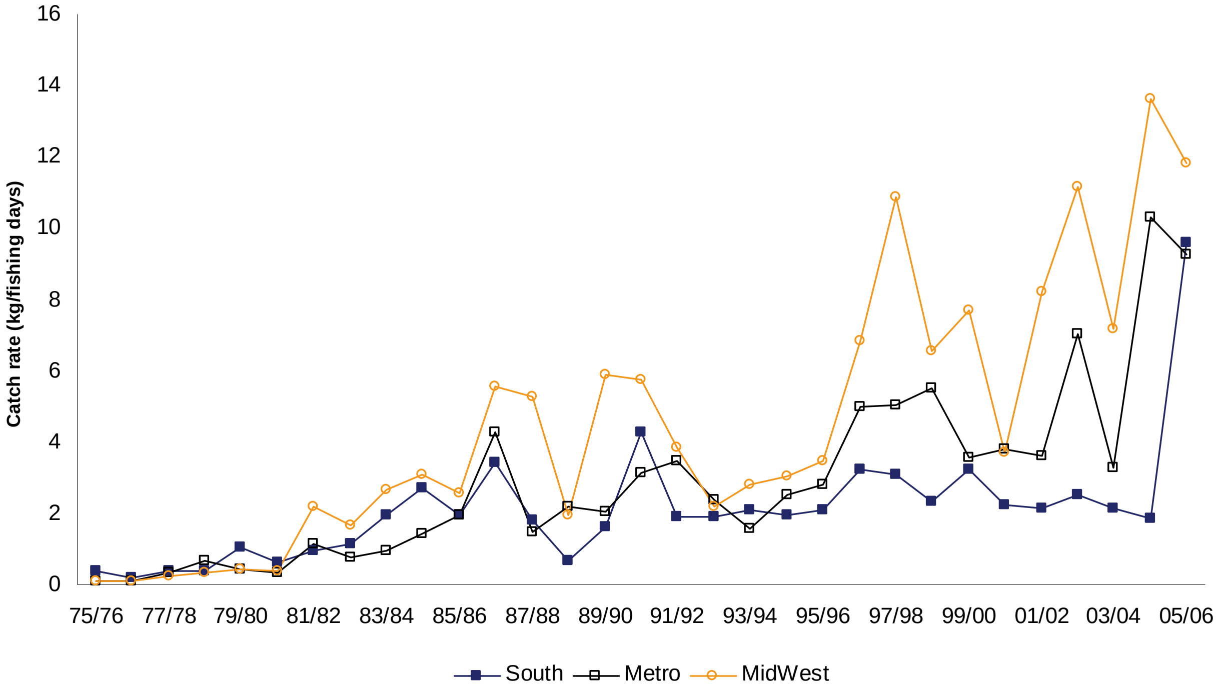


Figure 51. Commercial gillnet pink snapper catch rates by zone. See methods for details of zones, fishery and gear descriptions.

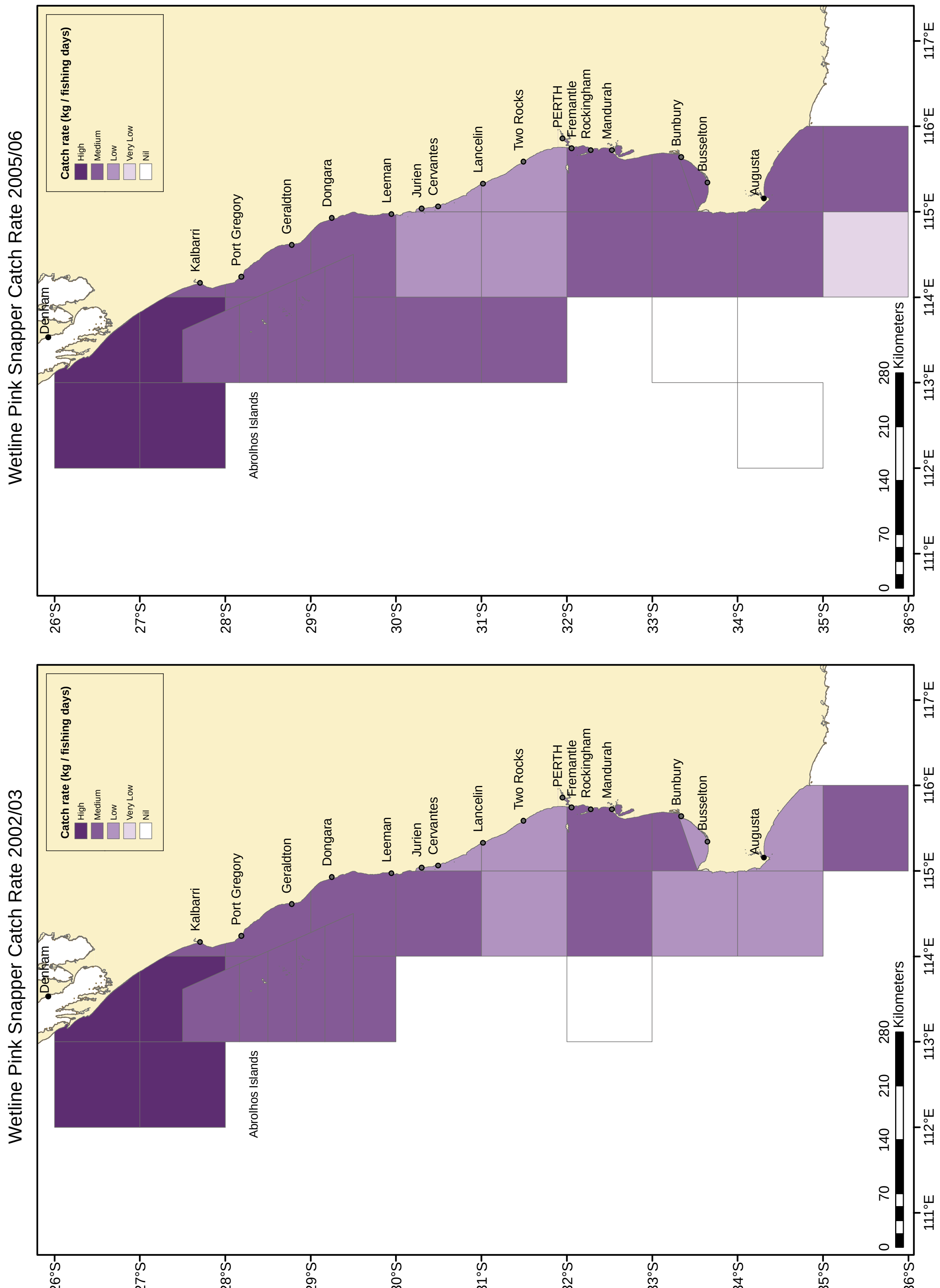


Figure 52. Commercial wetline (handline and dropline) pink snapper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

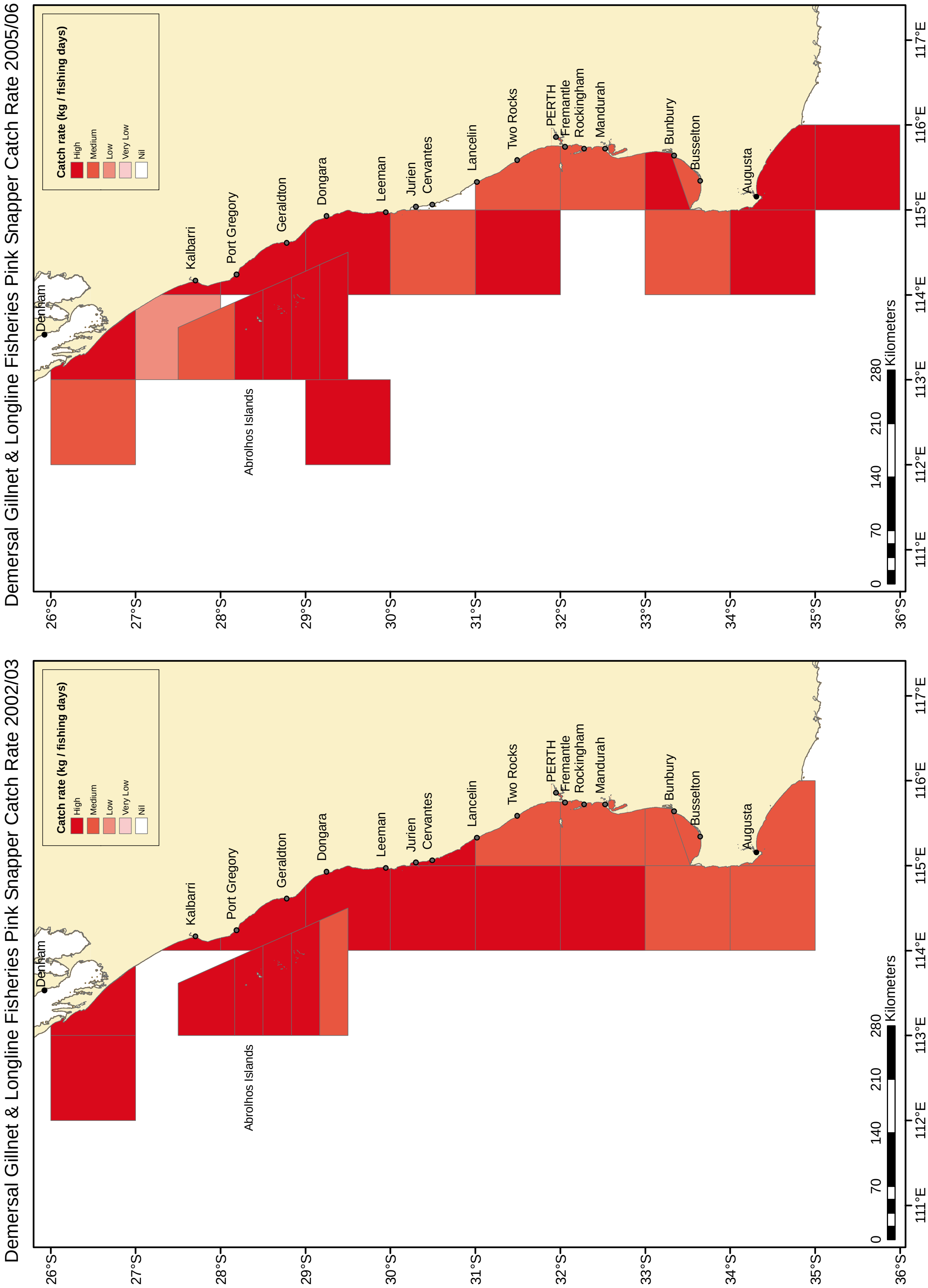


Figure 53. Commercial demersal gillnet and demersal longline fisheries pink snapper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

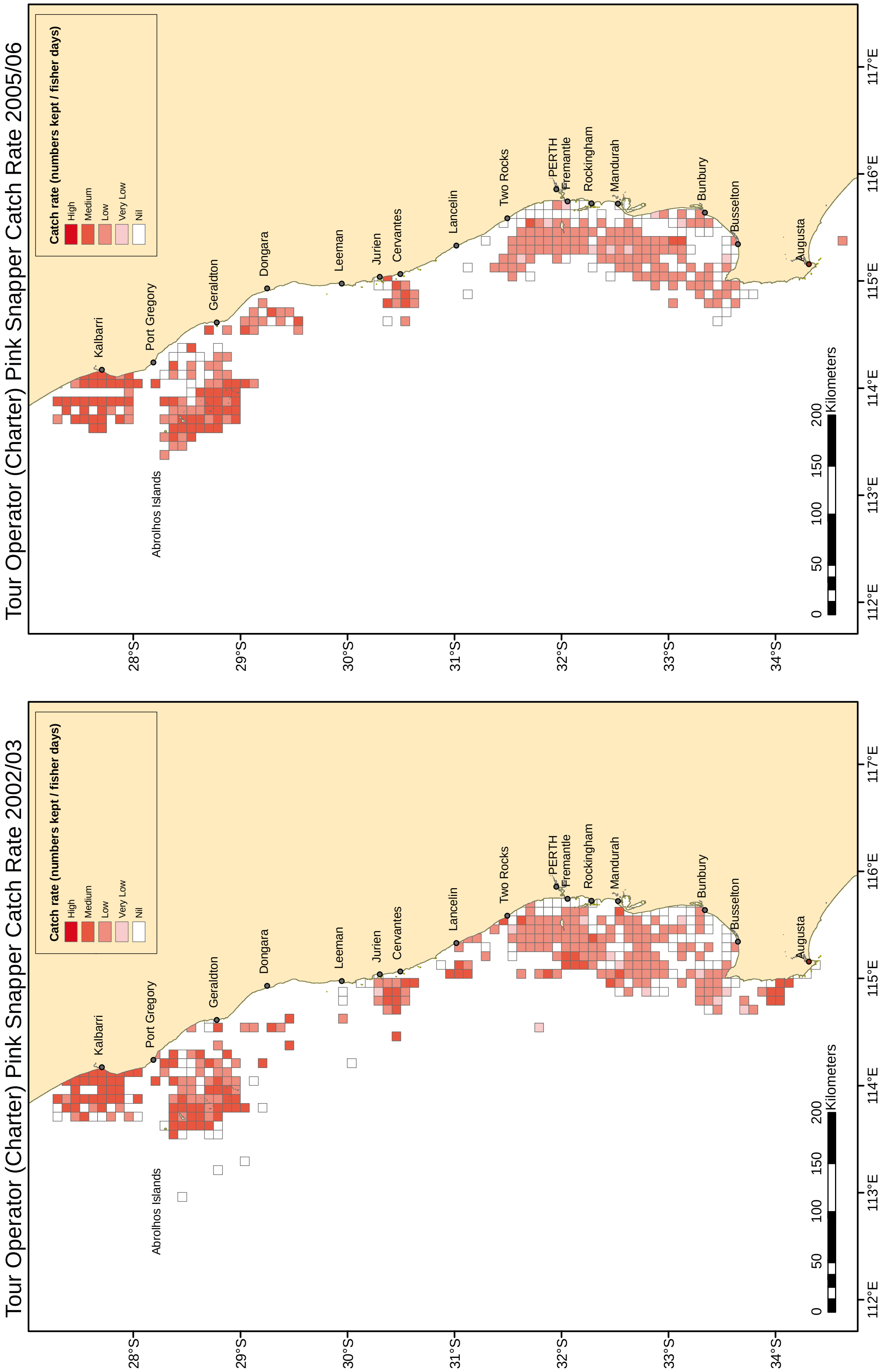


Figure 54. Tour operator (Charter) pink snapper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

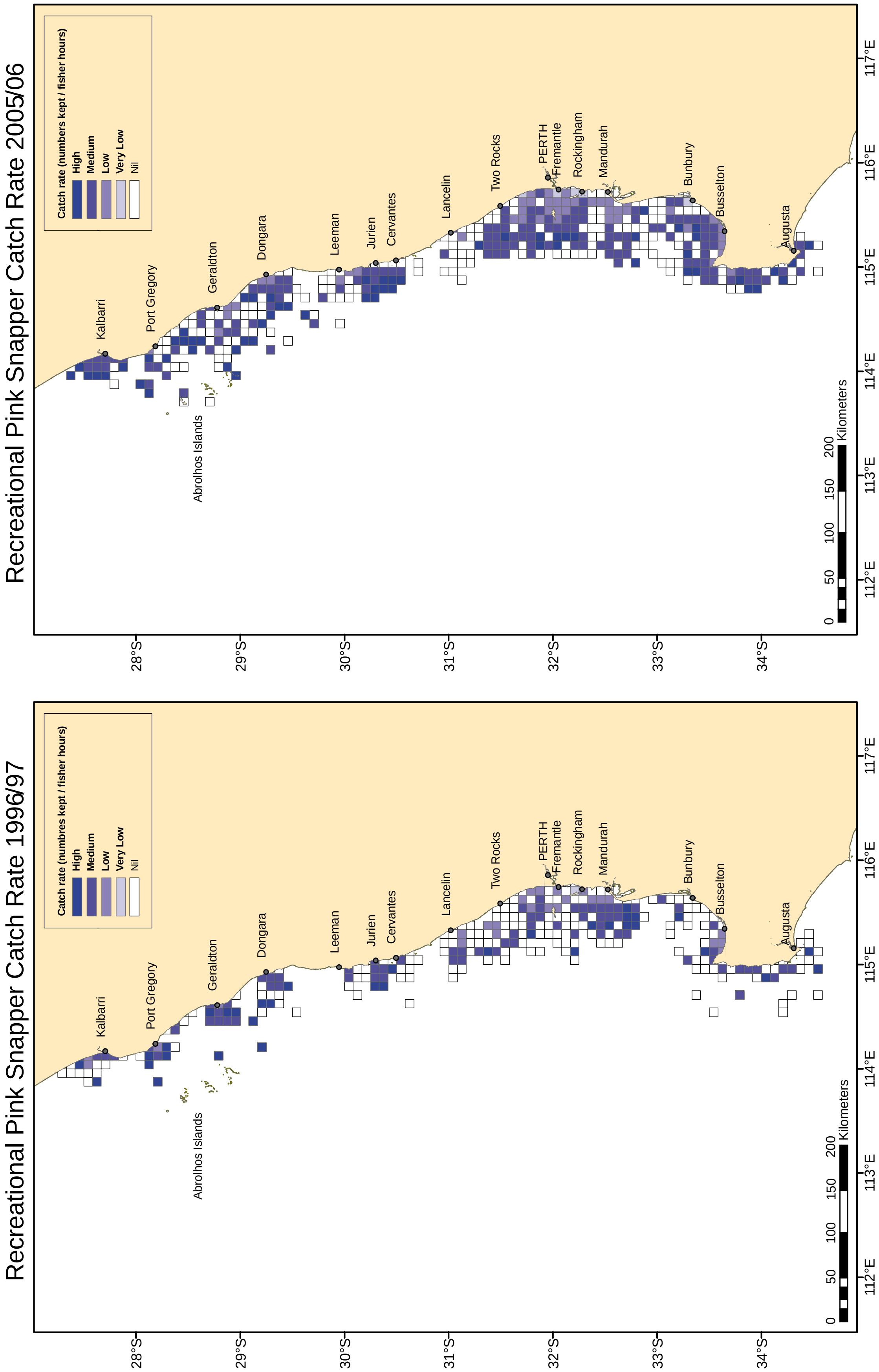


Figure 55. Estimated boat-based recreational pink snapper catch rates using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

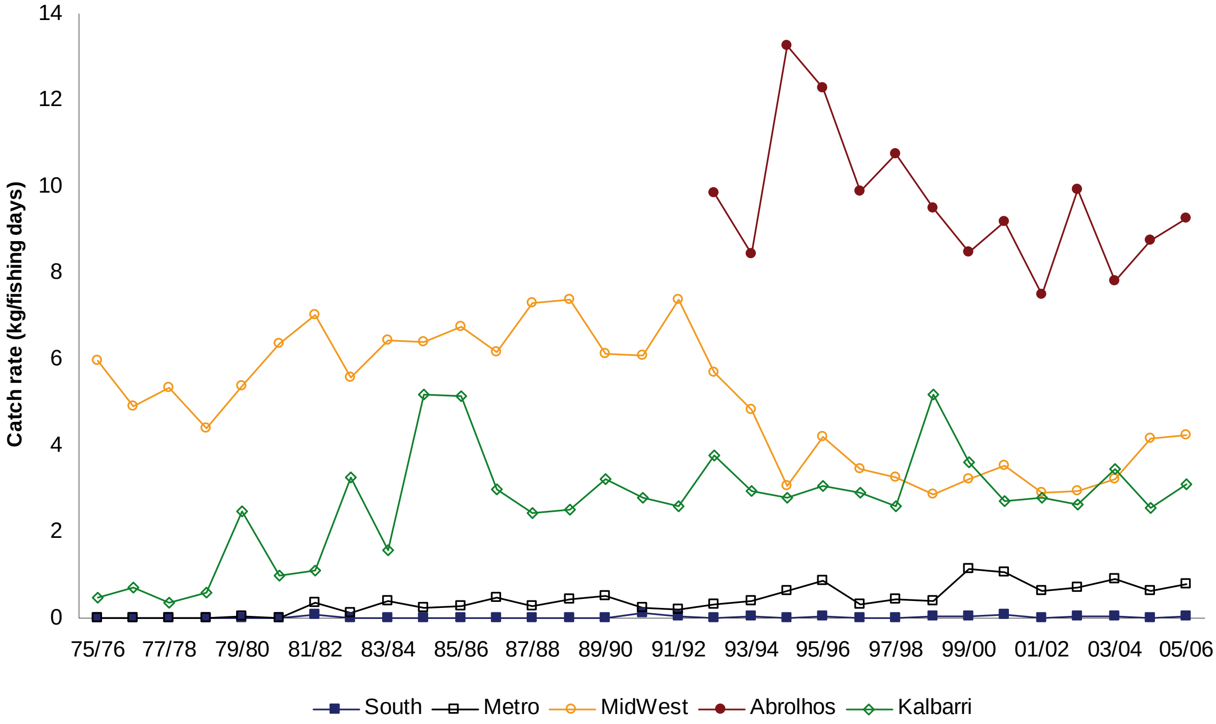


Figure 56. Commercial handline and dropline baldchin groper catch rates by zone. See methods for details of zones, fishery and gear descriptions.

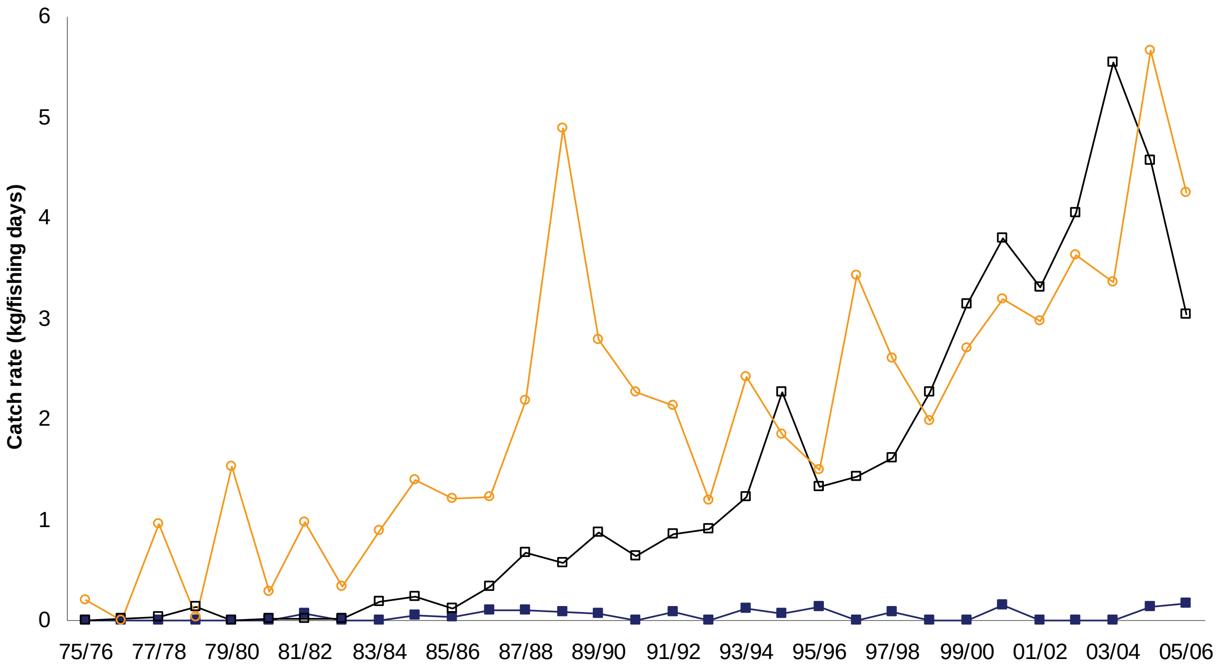


Figure 57. Commercial gillnet baldchin groper catch rates by zone. See methods for details of zones, fishery and gear descriptions.

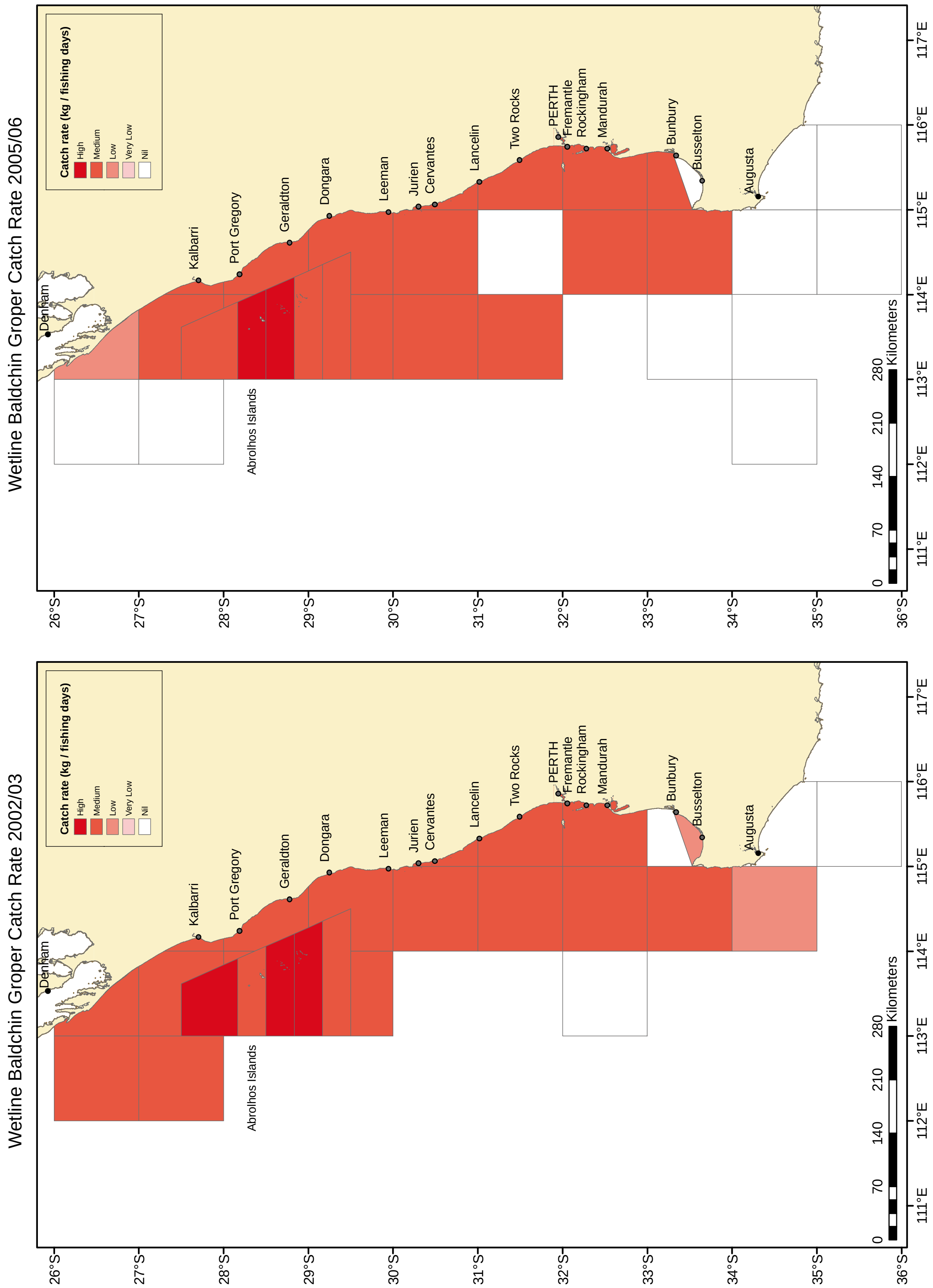


Figure 58. Commercial wetline (handline and dropline) baldchin groper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

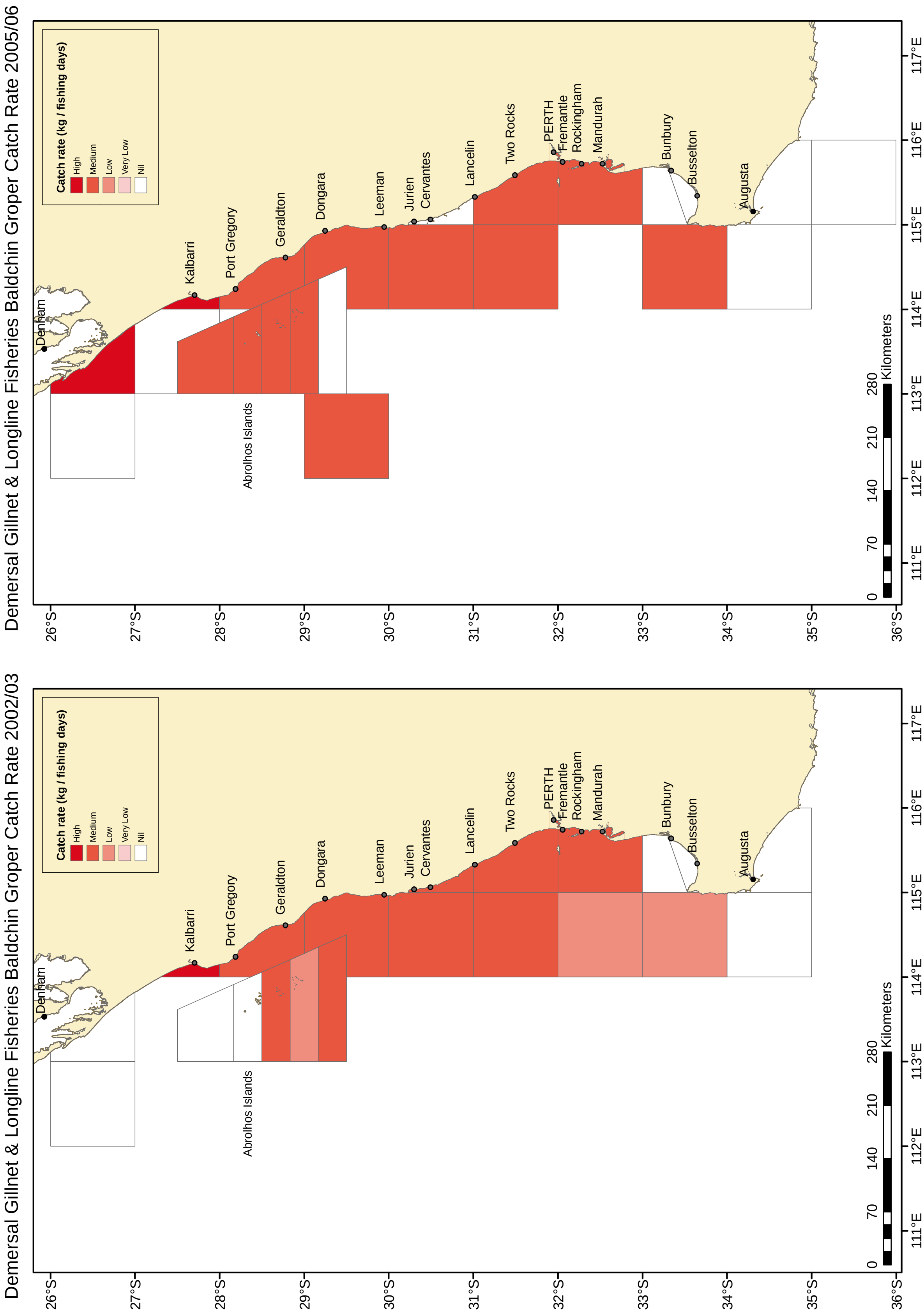


Figure 59. Commercial demersal gillnet and demersal longline fisheries baldchin groper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery and gear descriptions.

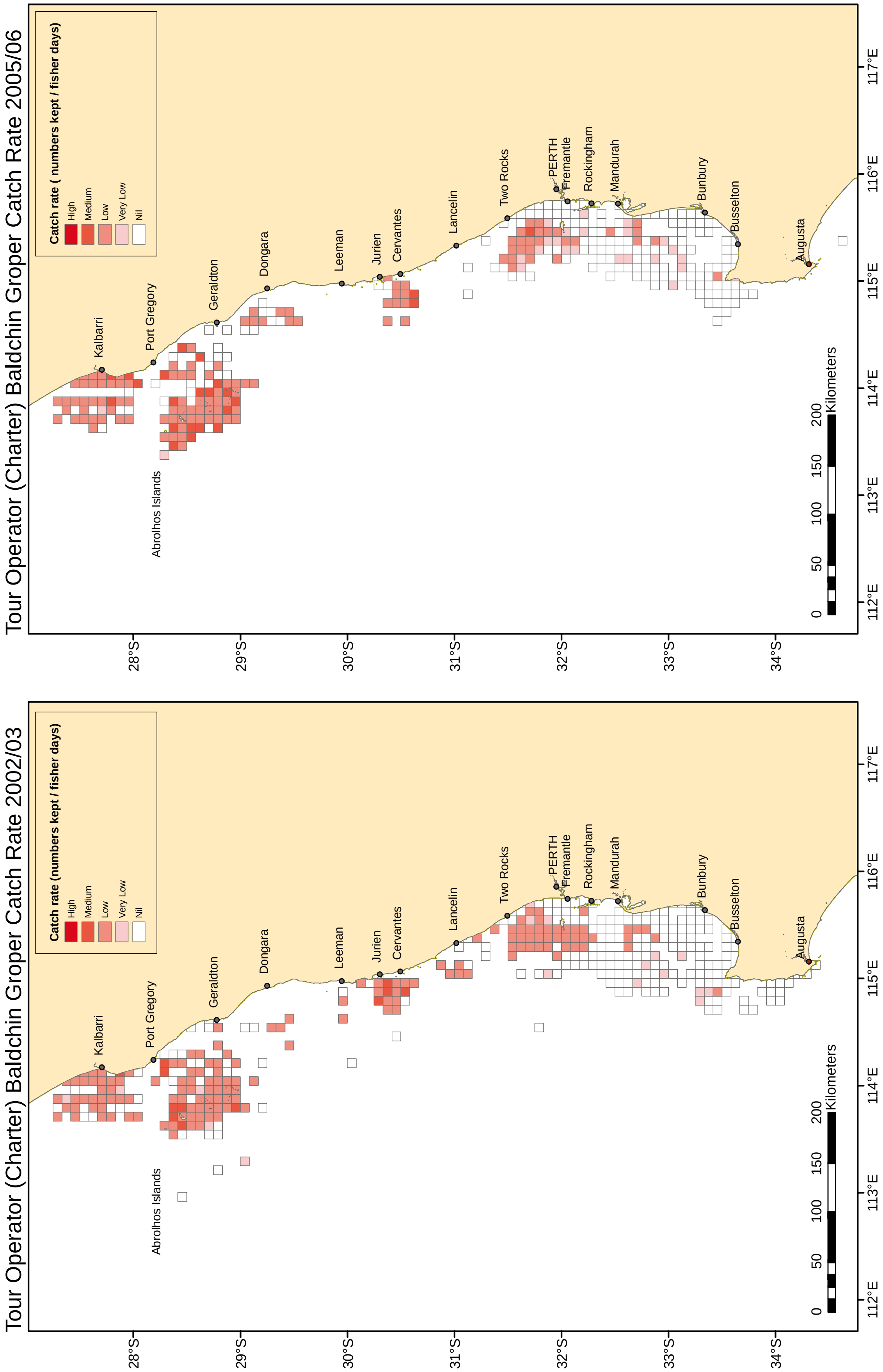


Figure 60. Tour operator (Charter) baldchin groper catch rates in the West Coast Bioregion for 2002/03 and 2005/06. See methods for details of fishery descriptions.

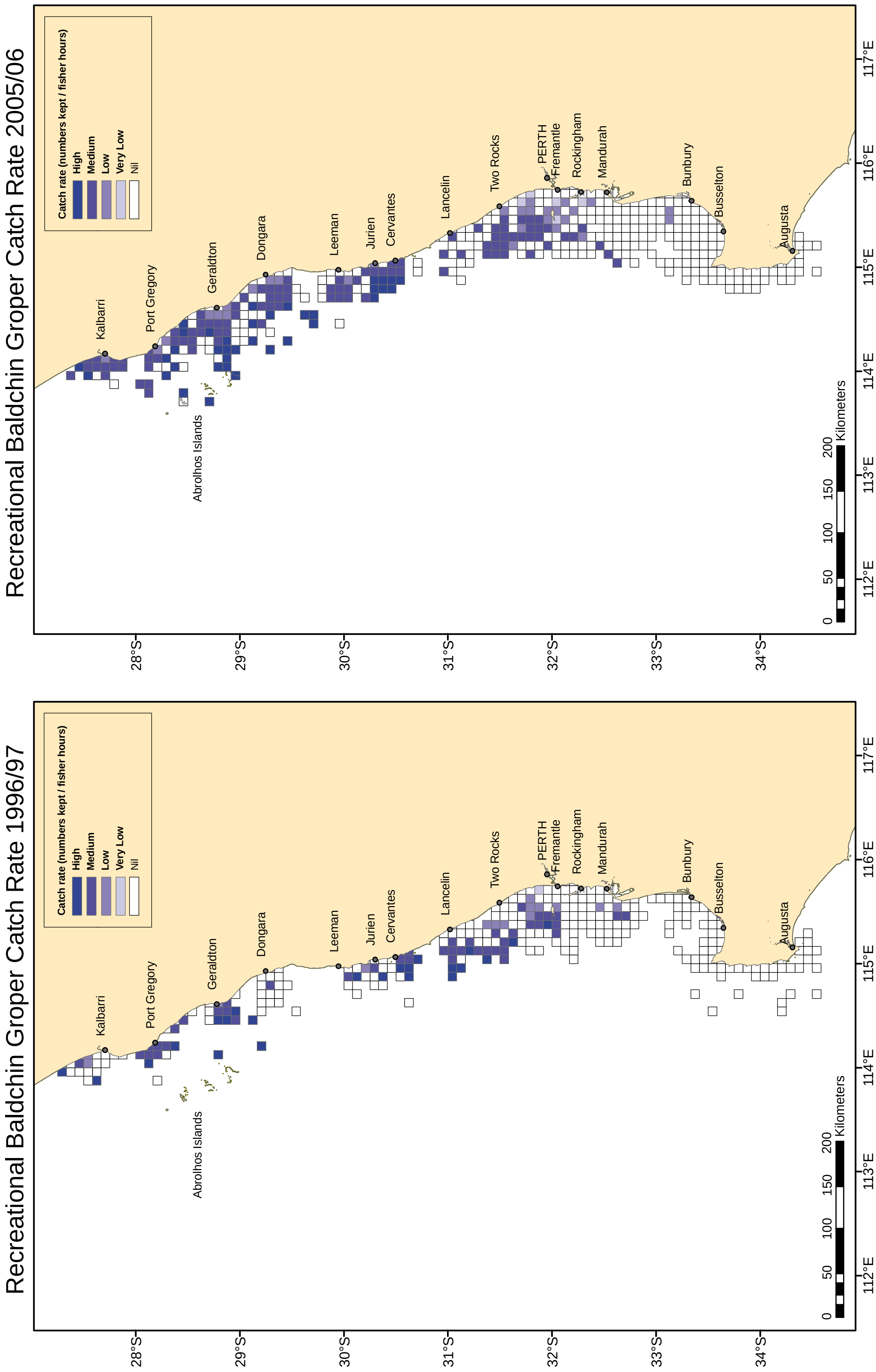


Figure 61. Estimated boat-based recreational baldchin groper catch rates using boat ramp creel surveys in the West Coast Bioregion for 1996/97 and 2005/06. See methods for details of survey descriptions.

5.0 Standardisation of commercial catch per unit effort data

5.1 Introduction

Non standardised catch rate data can often provide a misleading representation of the abundance of a fished population. However by using certain assumptions they can also be a useful input for stock assessment especially when no other information on historical shifts in stock abundance are available.

There are four major areas where catch-per-unit-effort data (CPUE) can provide a misleading indication of relative abundance:

(i) When the interaction between fishing method and fish behaviour results in the assumption of direct proportionality between CPUE and abundance is violated. Alternative scenarios are defined as “hyperdepletion,” where CPUE declines at a faster rate than stock abundance initially, and “hyperstability,” where CPUE can remain high initially while the stock abundance is declining (Hilborn and Walters 1992). Hyperdepletion can occur, for instance, where a fishery has locally depleted only a small available component of a stock, whereas hyperstability can arise where a mobile fleet can maintain high catch rates by continuing to move onto previously lightly-fished areas from heavily fished areas where localised depletion has occurred.

(ii) Technology creep increases the effective effort through the adoption of new technologies, such as more powerful vessels, mechanical reels, more efficient fishing methods and navigational aids. These factors can result in misleading results from CPUE analyses. Essentially, effort will be underestimated leading to inflated CPUEs.

(iii) The influence of other variables, such as weather on the catchability of fish.

(iv) Observation error, measurement error in the collection and entry of data, and process error in how CPUE is calculated.

Exploration of the influence of some of these factors on commercial catch and effort data was carried out to determine if reliable indices of stock abundance for the West Coast Demersal Scalefish indicator species could be produced. Preliminary statistical standardisations using Generalised Linear Models (GLMs) proved inconclusive as a result of the limited resolution in the commercial catch and effort data and are not presented. Future analysis will use additional data that are currently being collected in the form of daily logbooks to develop standardised indices of abundance.

Objectives

(i) To obtain information on those technologies that are considered most likely to have resulted in the greatest improvements in efficiency for catching scalefish in the commercial West Coast Demersal Scalefish Fishery (technologies include: global positioning systems (GPS), colour sounders and hydraulic reels).

(ii) To compile a list of those factors that commercial fishers think had the greatest influence on fishing efficiency, as a test of our assumption that the five surveyed technologies were indeed the most important factors influencing efficiency.

(iii) To use estimates from (i) and (ii) to adjust nominal (observed) annual effort into effective effort for those technologies considered by commercial fishers to be most influential in affecting fishing efficiency.

(iv) To explore trends in relative abundance of dhufish, pink snapper and baldchin groper in different management zones of the West Coast Bioregion using raw and adjusted CPUE, where adjusted CPUE data are calculated using effective annual effort estimates (from (iii)).

5.2 Methods

5.2.1 Survey on fishing efficiency

Commercial wetline fishers of the West Coast Demersal Scalefish Fishery were contacted by telephone and asked to participate in a survey on the efficiency of different fishing technologies for catching scalefish. Interviewees were selected randomly from a list of fishers known for using hook and line methods to target scalefish, which was obtained from CAES and the results of a previous survey (Cliff and Rome, unpublished data) . The survey was stratified by zone (Kalbarri, n = 8; Midwest, n = 8; Metro, n = 9; South, n = 9).

Fishers were asked the following questions:

(i) When did they commence fishing (year)?

(ii) For each technology (GPS, colour sounder, hydraulic reels, electric reels, electric auto-jigging):

- when did they first start using it?;
- how long did it take them until they felt that they could use it to the best of their ability? (hereafter referred to as "learning time"); and
- their estimate of how much, if any, it improved their fishing efficiency (defined below).

(iii) Could they list the five factors that have most influenced their fishing efficiency over the years, and could they please rank them (1 (most important) – 5 (fifth most important)).

Estimates of fishing efficiency were recorded as proportion improvements in the efficiency of their operation as a result of using this newly-adopted method. This change in efficiency could be quantified in two complimentary ways:

(i) the proportional decrease (p) in fishing time ($E(t)$) now to get the same quantity of catch as previously *i.e.* $E(t+1)=(1-p)E(t)$ (Type I), or

(ii) the proportional increase (p) in catch ($C(t)$) for the same amount of time spent fishing *i.e.* $C(t+1)=(1+p)C(t)$ (Type II),

These proportions could then be used to calculate proportional increase in efficiency according to the following:

$$Efficiency\_Increase = \begin{cases} \dfrac{p}{1-p} & \text{Type I} \\ p & \text{Type II} \end{cases} .$$

The increases in efficiency may not adequately represent the general change in practice (and efficiency) in the fishery, because such transitions are likely to occur over a number of years. Hence efficiency changes take place over two time scales:

(i) Within fishers: from the year that the fisher started using the technology until when that fisher felt that they were was using it to the best of their ability (*i.e.* optimum efficiency realised); and

(ii) Among fishers: from the earliest year that the technology is used to the latest year that it is adopted for the sample of fishers interviewed.

Within fisher data were obtained from learning time (*Learn_time*) data for each interviewed fisher, and summary statistics calculated.

Among fishers information was obtained by summarising data on the year that a technology was adopted for each fisher and among fishers for each technology.

An empirical model was fitted to proportional increase in the adoption of colour sounders and GPS among those fishers interviewed, with year. The proportion adopted data over years *y* were fitted to a standard logistic function:

$$P_{Adopted}(y) = \frac{\alpha}{1 + e^{\beta(\Delta t + 1) + \delta}},$$

where $P_{Adopted}(y)$ is the proportion of fishers who adopt a technology in year *y*,
Δt is the difference between year *y* and initial year that the technology was adopted,
α is an estimated parameter describing the asymptotic maximum $P_{Adopted}(y)$ for the survey period,

β , δ are estimated parameters describing the logistic curvature.

The trend of adoption of hydraulic reels differed and the proportion adopted data over years *y* were fitted to an exponential function:

$$P_{Adopted}(y) = \eta e^{\psi(\Delta t + 1)} + \phi$$

where η is an estimated parameter describing the magnitude of the exponential increase,
ψ is an estimated parameter describing the relative steepness of the exponential increase,

ϕ is an estimated parameter describing the $P_{Adopted}(y)$ at the initial year that the technology was adopted.

5.2.2 Transforming nominal effort data into effective effort data

Data on efficiency estimates and modelled proportion of fishers adopting different technologies were used to transform nominal (observed effort) into effective effort data (accounting for improvements in fishing efficiency due to the adoption of new technologies). Nominal effort was the time series of catch rates calculated for wetline (combined handline and dropline) from the previous section.

Effective effort for a particular year *y* was calculated by accounting for effective increases (*Efficiency_Increase*) in the nominal effort (*Nom_Effort*) as:

$$Effective\_Effort(y) = Nom\_Effort(y) * (1 + \mathrm{P}_{\mathrm{Adopted}}(\mathrm{y}) * Efficiency\_Increase) .$$

Efficiency increase is calculated as $P_{Adopted}(y) = \dfrac{\alpha}{1 + e^{\beta(\Delta t + 1 + Lag - Learn\_time) + \delta}}$ for GPS and colour sounders, $P_{Adopted}(y) = \eta e^{\psi(\Delta t + 1 + Lag - Learn\_time)} + \phi$ for hydraulic reels,

where:

$P_{Adopted}(y)$ is the proportion of fishers who adopt a technology in year y,
Δt is the difference between year *y* and initial year that the technology was adopted,
α is an estimated parameter describing the asymptotic maximum $P_{Adopted}(y)$ for the survey period

β , δ are estimated parameters describing the logistic curvature

η is an estimated parameter describing the magnitude of the exponential increase,

ψ is an estimated parameter describing the relative steepness of the exponential increase,

ϕ is an estimated parameter describing the $P_{Adopted}(y)$ at the initial year that the technology was adopted,
Learn_time is the median of learning times estimated by interviewed fishers for learning that technology from adoption to full efficiency,
Lag is adjustment to account for converting calendar year to financial year
Efficiency_Increase is the median percent increase in effective effort due to the adoption of that technology.

5.3 Results

5.3.1 Efficiency survey

The top five factors identified by interviewed fishers as having the most influence on fishing efficiency were (in descending order): GPS, colour sounder, boat, hooks, line, hydraulic reels, experience, and bait (Figure 62). GPS and colour sounder were frequently mentioned in all zones while boats, experience and hooks were only mentioned in some zones (Figure 63). The most important factor identified in all zones was clearly GPS (Figures 64 and 65). Note, however, the relatively small sample sizes for between zone comparisons.

Some interviewed fishers could not provide estimates of efficiency due to their lack of relevant fishing history prior to the uptake of surveyed technologies (i.e. GPS, colour sounder, hydraulic reels, electric reels) or chose not to answer the questions for some other reason (Table 2). Most interviewed fishers provided estimates for 2 or 3 technologies (Table 2).

Among interviewed fishers (and among zones), black and white sounders were adopted from 1955, hydraulic reels from 1975, colour sounders from 1980 and GPS from 1989 (Figure 66). For some interviewed fishers, there have been more recent improvements in efficiency from updated models of colour sounder (1992 onwards) and GPS from 1993. However, Figure 66 does not adequately represent the duration over which the adoption of each technology occurred, because data for some interviewed fishers who have recently entered the fishery and thus have acquired the gear concomitantly have been included. Therefore the adoption of such technologies by these interviewed fishers will be more recent and explained by their entry into the fishery rather than explain the transition to different technologies within the fishery.

The period over which this transition occurs for each technology is more representative in Figure 67, where only data from those interviewed fishers that adopted the use of a new technology after at least two years of operation were analysed. Compared to hydraulic reels and colour sounders, GPS was adopted over a shorter nine-year period (Figure 67). The earliest, median, and latest years of adoption of each technology are provided in Table 3. Within interviewed fishers, there were sufficient data to estimate learning times for GPS, colour sounders and hydraulic reels, with hydraulic reels taking less time to master than GPS and colour sounders taking the longest to master (Table 4).

There was adequate distribution of efficiency improvement estimates (i.e., the estimated improvements in fishing efficiency as a result of adopting a technology) across zones for colour sounders, GPS and hydraulic reels (Table 5). Median estimates of efficiency improvement for colour sounders, GPS and hydraulic reels were 22%, 77% and 25% and respectively, across all zones (Table 5). There were too few data to compare estimates among zones. There are low sample sizes for other technologies (Table 5).

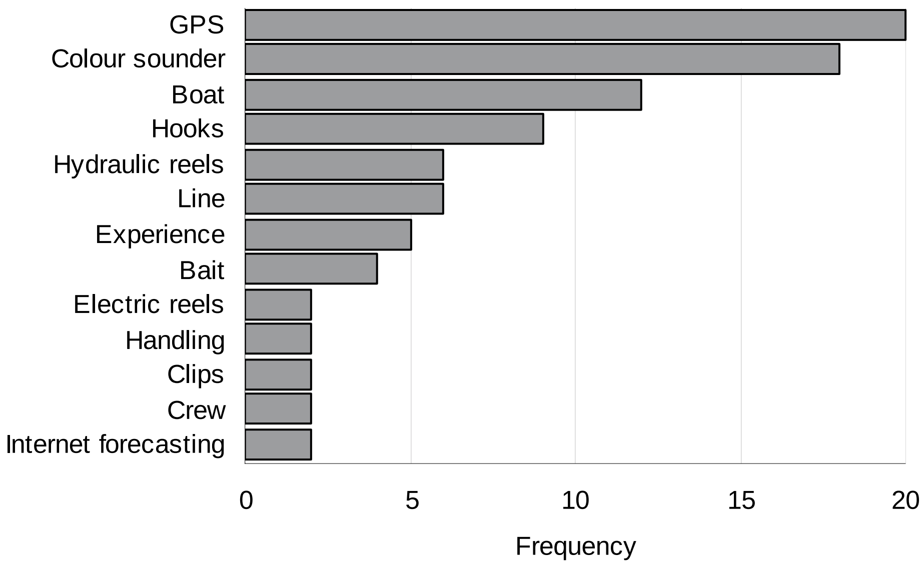


Figure 62. Factors most frequently mentioned in top 5 by interviewed fishers influencing efficiency.

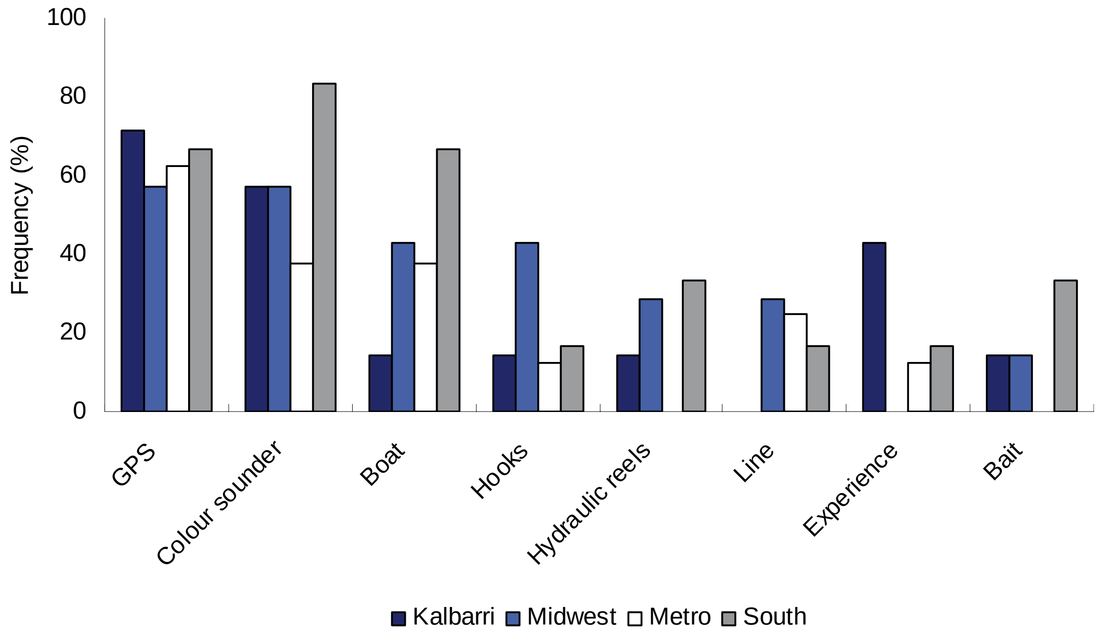


Figure 63. Factors most frequently mentioned in top 5 by interviewed fishers influencing efficiency in each zone.

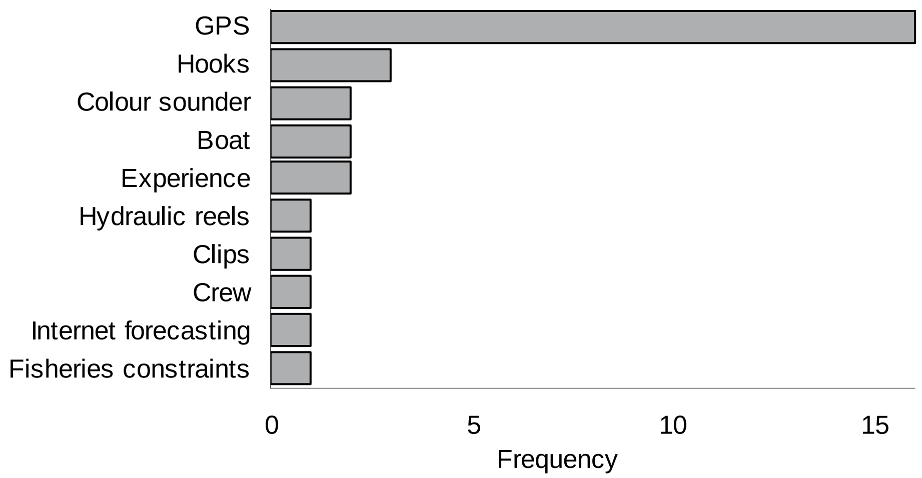


Figure 64. Important factors identified by interviewed fishers influencing efficiency.

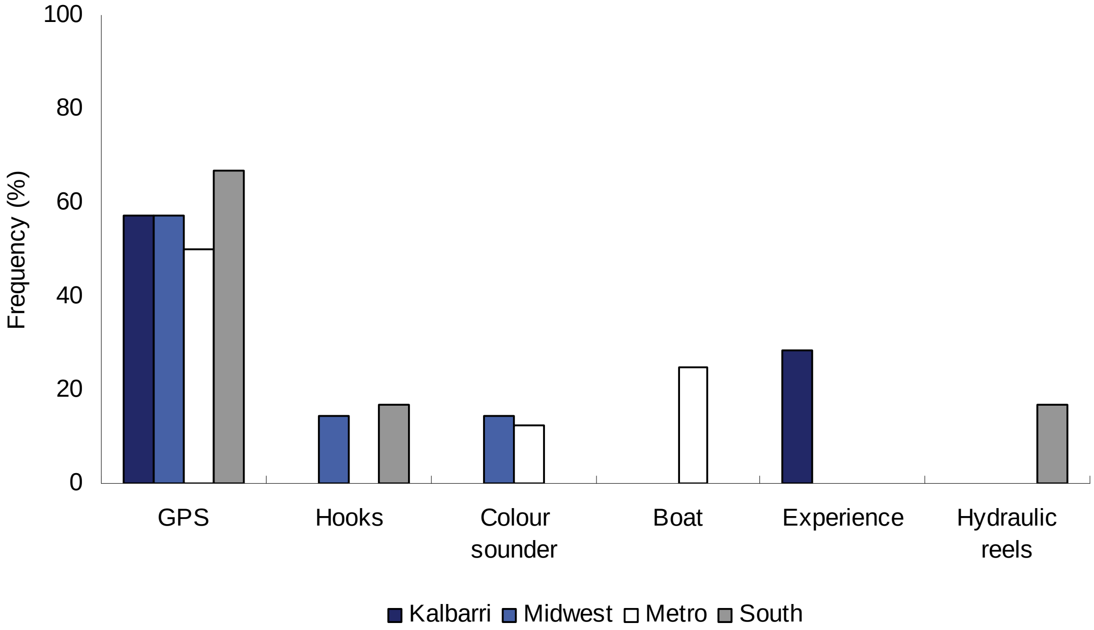


Figure 65. Important factors identified by interviewed fishers influencing efficiency in each zone.

Table 2. Number of efficiency estimates provided per zone. Eleven of 34 interviewed fishers did not provide efficiency estimates.

Efficiency estimates	Kalbarri	Metro	Midwest	South	Total
0	3	3	2	3	11
1	0	2	1	1	4
2	2	2	4	1	9
3	3	2	0	3	8
4	0	0	0	1	1
5	0	0	1	0	1
Total	8	9	8	9	34

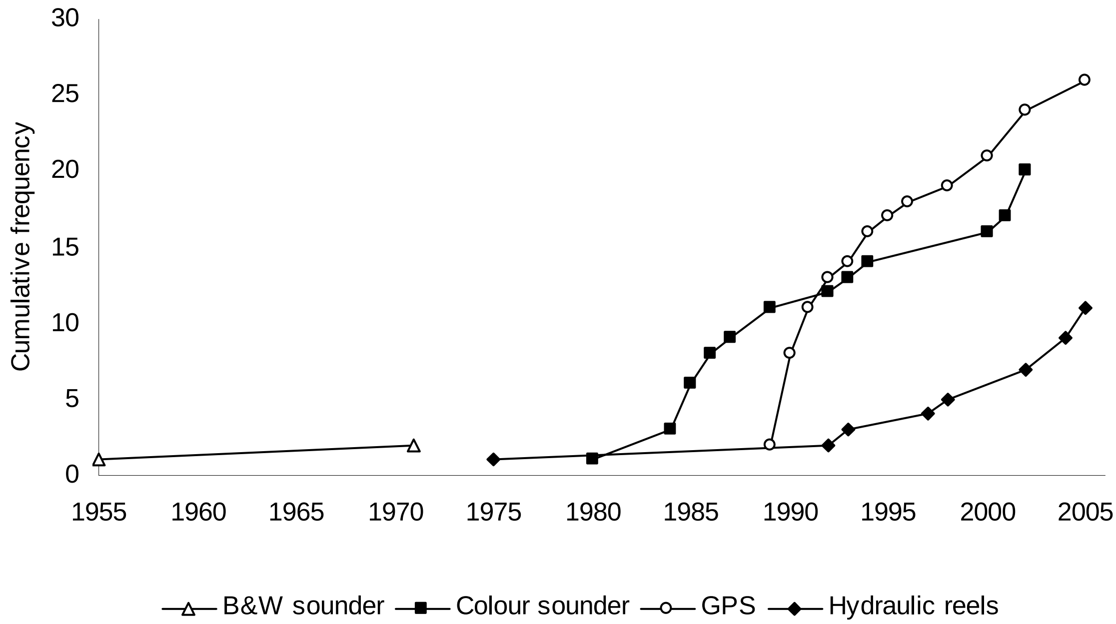


Figure 66. Cumulative uptake of different technologies by interviewed fishers.

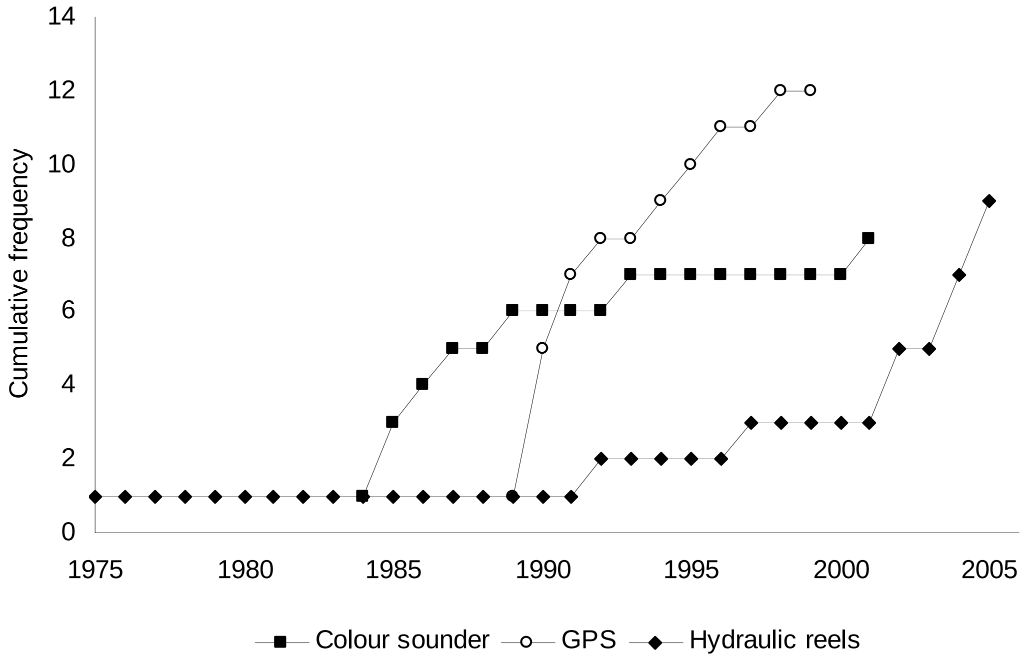


Figure 67. Cumulative uptake of different technologies by interviewed fishers that adopted the use of a new technology after at least two years of operation.

Table 3. Periods of shifts to colour sounder, GPS and hydraulic reels by interviewed fishers.

	Min	Median	Max	Range	n
Colour sounder	1980	1989	2002	22	23
GPS	1984	1993	2005	21	29
Hydraulic reels	1975	2000	2005	30	12

Table 4. Mean and median learning time (days) for colour sounder, GPS and hydraulic reels by interviewed fishers.

	n	Median	Mean	SE
Colour sounder	15	365	339.17	92.15
GPS	22	180	259.32	79.57
Hydraulic reels	9	7	36.78	22.02

Table 5. Proportional improvements in efficiency for colour sounder, GPS and hydraulic reels. Due to non-normality the median statistics are recommended for use.

Method	n	Min	Median	Mean	SE	Max
Colour sounder	16	0.0	0.22	0.39	0.13	1.5
GPS	20	0.0	0.77	1.33	0.47	9.0
Hydraulic reels	10	0.0	0.25	0.64	0.30	3.0

5.3.2 Modelled trends of increases in efficiency over time

Models describing the trend of cumulative adoption of colour sounders, GPS and hydraulic reels within the interviewed fishers are presented (Table 6, Figure 68). The highest proportion of each technology adopted was 0.96 in 2006, 0.97 in 1998 and 0.44 in 2006 for colour sounder, GPS and hydraulic reels respectively (Figure 68).

Table 6. Empirical model estimates describing the adoption of colour sounder, GPS and hydraulic reels.

Technology	Equation
Colour sounder	$P_{Adopted}(y) = \frac{0.918}{1+e^{-0.493(Year-1980+1)+2.251}}$
GPS	$P_{Adopted}(y) = \frac{1}{1+e^{-0.531(Year-1984+1)+3.821}}$
Hydraulic reels	$P_{Adopted}(y) = 0.011e^{0.143(Year-1975+1)} + 0.147$

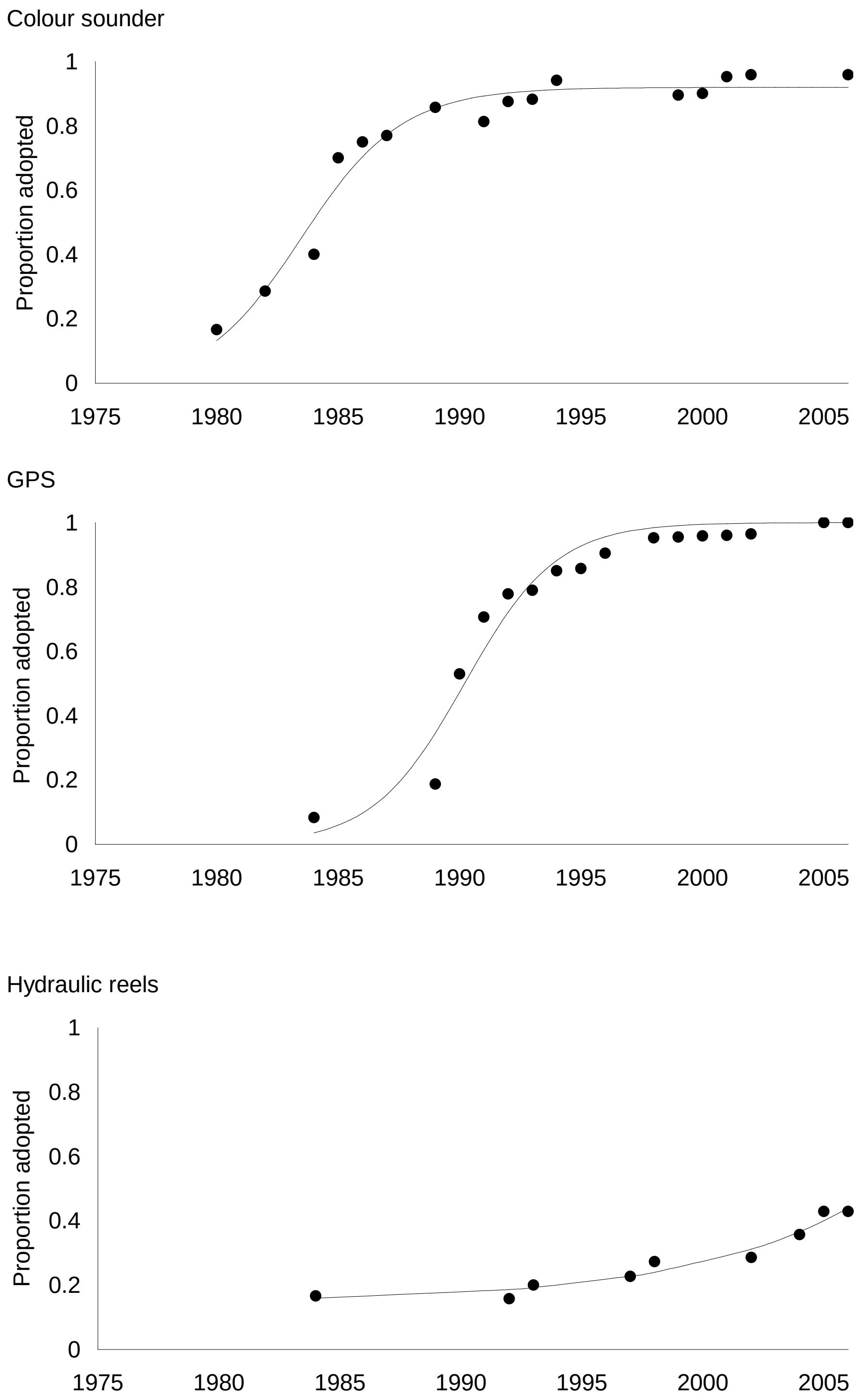


Figure 68. Empirical model describing the adoption of colour sounder, GPS and hydraulic reels. Refer to Table 6 for equations.

5.3.3 Adjusted catch rates

Effective effort due to increases in efficiency as a result of fishers adopting colour sounders, GPS and hydraulic reels were calculated using the estimates presented in Table 7. Time series of commercial catch rates adjusted for the adoption of colour sounders, GPS and hydraulic reels for dhufish, pink snapper and baldchin groper are shown in Figures 69-71.

Table 7. Estimates for calculating effective effort for colour sounders, GPS and hydraulic reels. Refer to methods for descriptions of variables.

Variables	Colour sounder	GPS	Hydraulic reels	Reference
Initial year	1980	1984	1975	Table 3
Median Learn_time (years)	1	0.5	0.02	Table 4
Median Efficiency_Increase	0.22	0.77	0.25	Table 5
α	0.918	1.000		Table 6
β	-0.493	-0.531		Table 6
δ	2.251	3.821		Table 6
η			0.011	Table 6
ψ			0.143	Table 6
ϕ			0.147	Table 6
Lag	0.5	0.5	0.5	

Adjusted commercial wetline catch rates of dhufish have been variable between 1975/76 and 2005/06 with Kalbarri and Abrolhos zones suggest a slight increasing trend while the Midwest, Metro and South zone indicate a declining trend over that period (Figure 69).

Adjusted commercial wetline catch rates of pink snapper have been highly variable between 1975/76 and 2005/06 however overall the Abrolhos and South zones remained steady while the Kalbarri, Midwest and Metro zones indicate a declining trend over that period (Figure 70). Note that while overall Abrolhos adjusted catch rates for pink snapper overall appear to be steady, in recent years they are actually increasing.

Adjusted wetline catch rates of baldchin groper have been variable between 1975/76 and 2005/06 with the Midwest and Abrolhos zones indicating a substantial decline while overall the Kalbarri, Metro and South zones remained steady over that period (Figure 71).

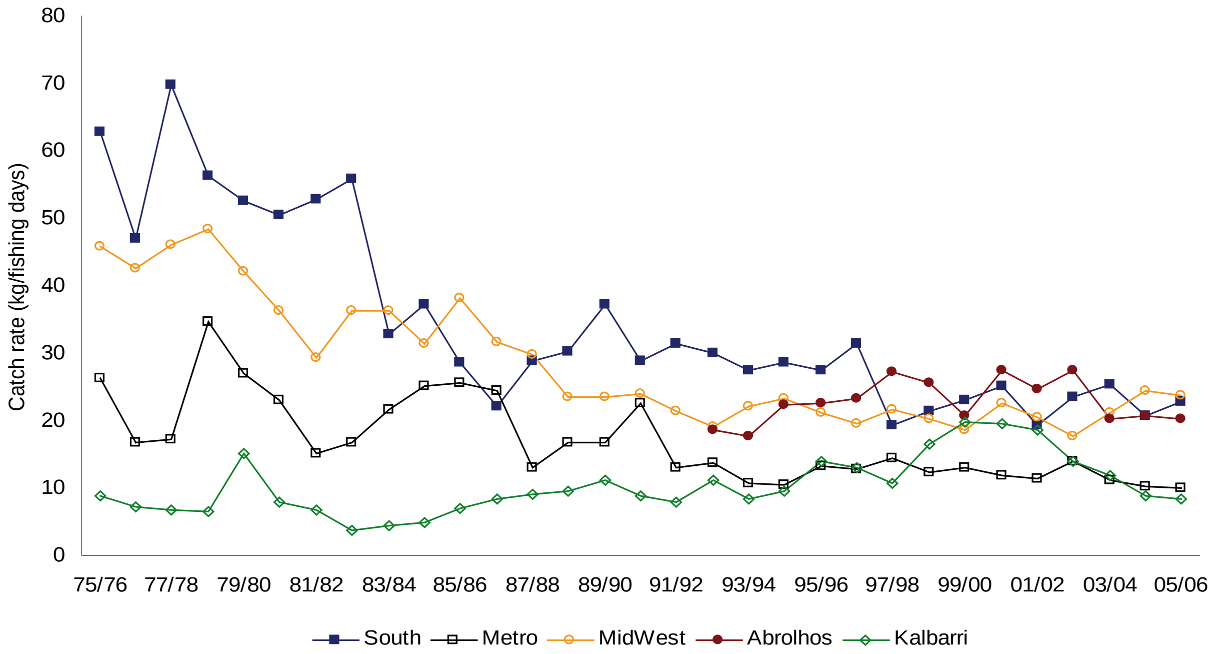


Figure 69. Commercial handline and dropline dhufish catch rates by zone accounting for efficiency increases due to adoption of colour sounders, GPS and hydraulic reels. See methods for details of zones, fishery, gear and technology descriptions.

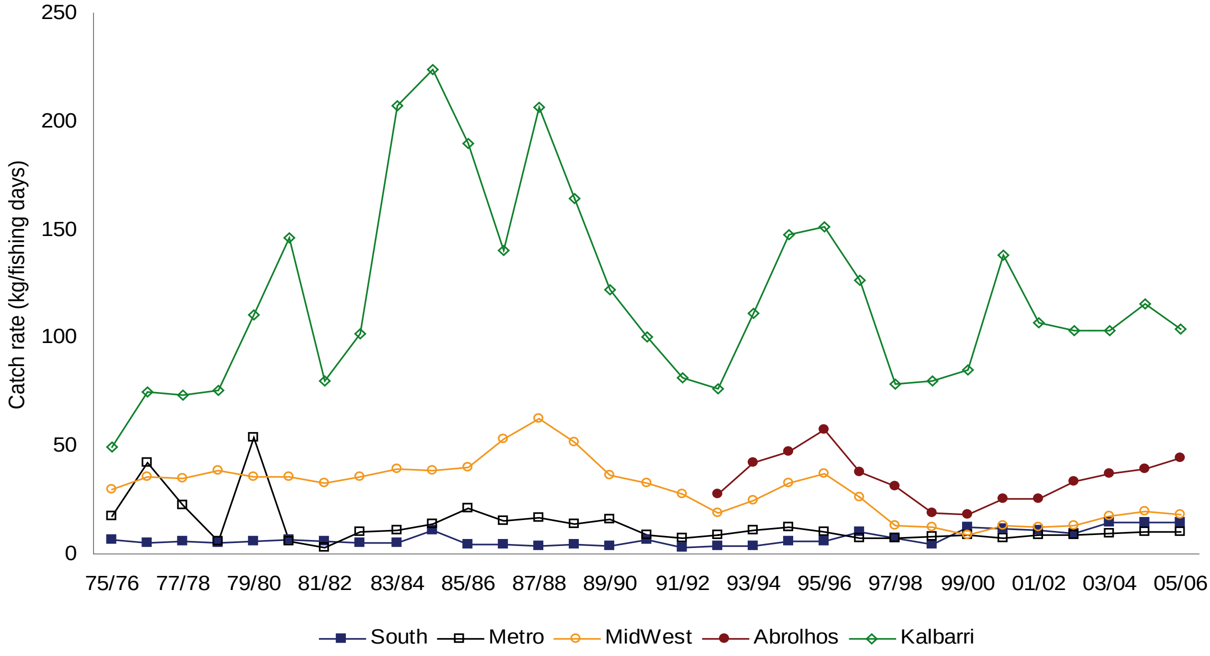


Figure 70. Commercial handline and dropline pink snapper catch rates by zone accounting for efficiency increases due to adoption of colour sounders, GPS and hydraulic reels. See methods for details of zones, fishery, gear and technology descriptions.

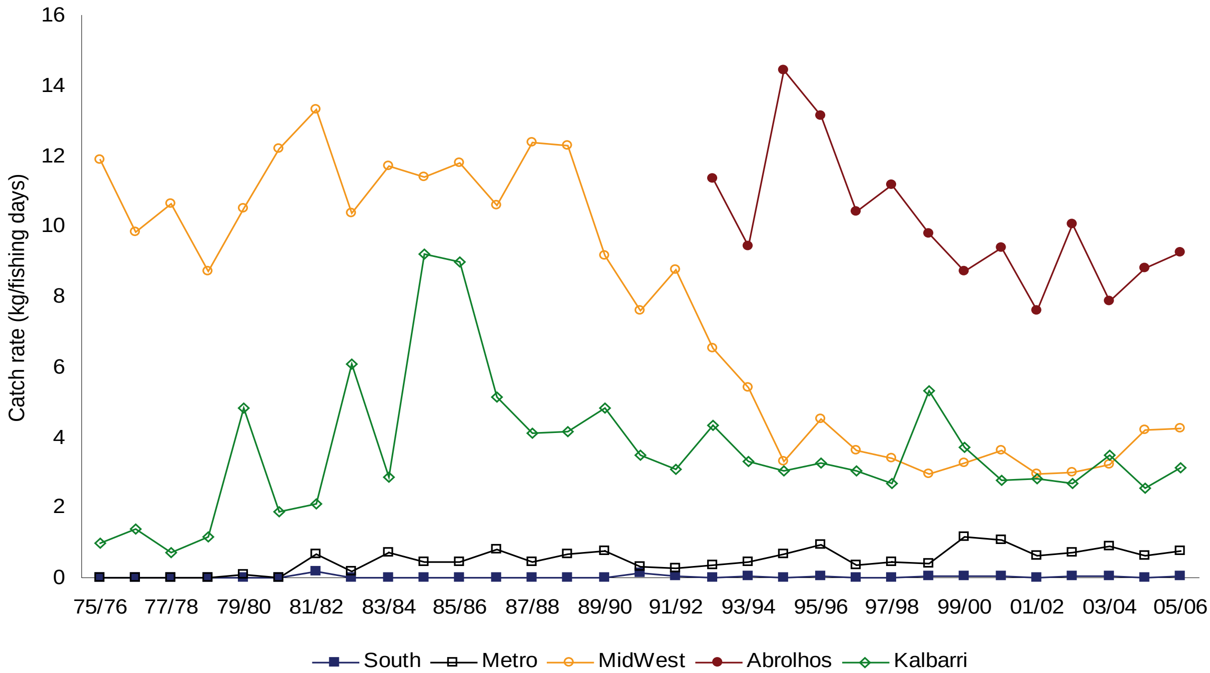


Figure 71. Commercial handline and dropline baldchin groper catch rates by zone accounting for efficiency increases due to adoption of colour sounder, GPS and hydraulic reels. See methods for details of zones, fishery, gear and technology descriptions.

5.4 Discussion

Increased efficiency due to the adoption of colour sounders, GPS and hydraulic reels were observed to influence the overall net change in catch rates between 1975/76 to 2005/06. The greatest changes were observed in the Midwest and Metro zones for dhufish and Kalbarri, Midwest and Metro for pink snapper where the adjusted wetline catch rates indicate declines whereas the nominal catch rates remain steady or increased over the same period.

Since the majority of the commercial catch of dhufish, pink snapper and baldchin groper is taken by wetline handline and dropline the trends exhibited by the adjusted catch rates may provide some indices of abundance. The declines in adjusted catch rates for dhufish occur in the Midwest, Metro and South zones indicate there may be declines in abundance of dhufish in these zones. Similarly the declines in adjusted catch rates for pink snapper in the Kalbarri, Midwest and Metro zones suggest there may also be declines in abundance of pink snapper in these zones. Declining nominal catch rates and adjusted catch rates for baldchin groper in the Midwest and Abrolhos zones indicate that abundance of this species may be declining in these zones

The possibility of hyperdepletion and/or hyperstability remains, and if this is the case, current adjusted catch rates might not adequately reflect underlying trends in relative abundance. This problem can be addressed by the collection of catch and effort data with increased resolution. For instance, new logbooks that are currently being trialled among commercial wetline fishers provide scope for catch and effort data to be recorded at much finer spatial and temporal scales.

The attempts at standardisation of catch rates using GLMs should be continued. While the limited resolution in the commercial catch and effort data resulted in reduced degrees of freedom and statistical power of the preliminary GLMs, fine scale information on catch and effort data will result in the increased degrees of freedom required for more complex GLMs. Such GLMs might have alternative discrete treatment variables with many levels, such as vessel or interaction terms included to explore the influence of, for example, using different methods in particular months. Certainly other additional data sets could be included as terms within the GLM for further refining these standardised indices of abundance, and given time and resources, these alternative models should be explored.

These analyses, although currently representing the best available evidence of trends in adjusted catch rates of dhufish, pink snapper and baldchin groper, should be considered as more of a starting point for obtaining estimates of relative abundance in future. The identification of shortcomings in the current data set for such an analysis emphasised the importance of collecting catch and effort data with increased resolution.

6.0 Review of the length and age frequency data and estimation of total mortality from age samples

6.1 Introduction

The sustainability of a stock cannot be assessed using formal comprehensive mathematical stock assessment models without an extended time series of good quality fisheries catch and effort data. In such circumstances biomass estimates are not determined and an alternative approach is to use age and length frequency samples to gain information on recruitment variation, relative depletion levels, and the current age and length structure underlying the fishery. The theoretical age compositions corresponding to unfished, target and limit reference points (Table 1) are presented in Figure 72.

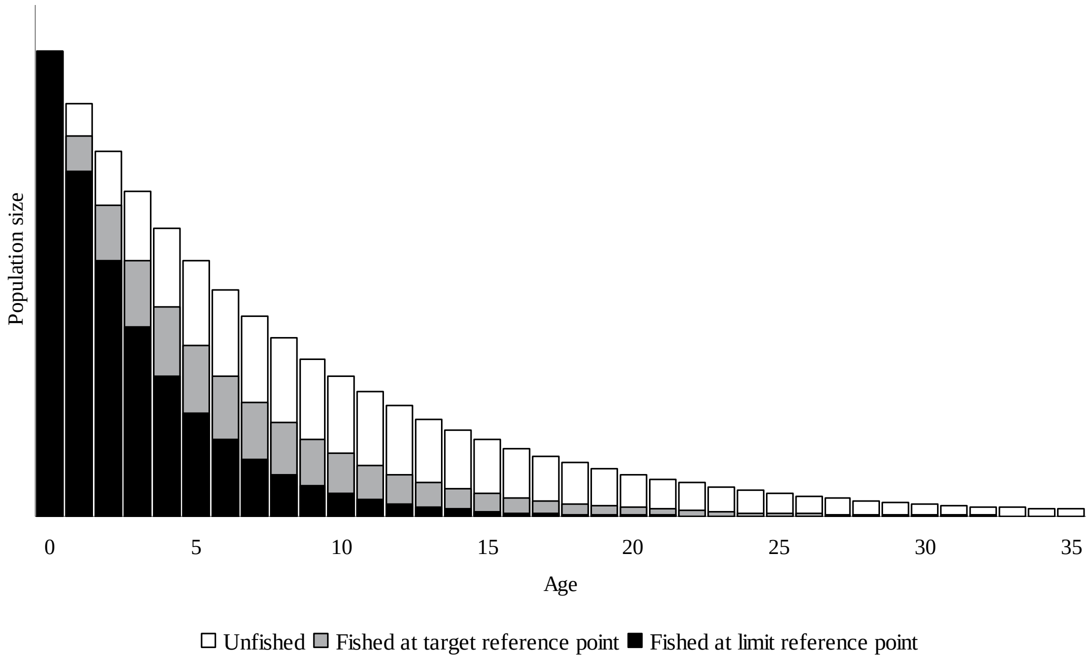


Figure 72. Theoretical age compositions of an unfished population and populations fished at target and limit reference points (Table 1).

The age structure of a population can be used to produce an estimate of the total mortality (natural mortality together with fishing mortality) on the fully-selected age classes. Where estimates of natural mortality can be derived for the species, estimates of fishing mortality can be derived, which, in combination with the other available information, can be used to assess whether over-fishing is occurring or whether there is a risk that this will happen (Figure 72). These analyses assume that the age data are derived from a representative sample of the population.

The sampling design used to obtain age data is fundamental to ensuring robust conclusions. These data can be collected using fishery-dependent (those arising as a direct result of fishing operations) or fishery-independent (requiring surveys or observations independent of fishery operations).

The main assumption of fishery-dependent sampling is that the catch is representative of the fished population. If the fishing method or location of fishing differs between fishing sectors then samples should either represent sectors proportionally or sectors should be sampled separately. In the West Coast Bioregion the majority of dhufish, pink snapper and baldchin groper are caught by hand line and drop line methods. In 2005/06, 52% of the dhufish catch 20% of the snapper catch and 54% of baldchin groper catch were caught by recreational fishers (including charter boats), however the proportion of catches from each sector varies between zones.

Legal minimum sizes in the West Coast Bioregion fisheries, result in catches from each sector comprising mostly adult dhufish, adult and sub-adult pink snapper and adult baldchin groper. Although fishery-independent sampling can be used to sample fish from the entire population, it is often used in conjunction with fishery-dependent samples to target individuals that are not captured in the fishery, such as juvenile and undersize fish, to obtain a complete representation of the fish population for use in determining growth parameters.

In order to provide any significant resolution and characterise the age distribution of a species, the minimum sample size to be collected and aged is between 288 and 512 (Craine *et al*. 2007). Such numbers are required to control the amount of random variation from sample to sample originating from the same population. The estimate of sample size is determined by the Kolmogorov-Smirnov statistic for cumulative precision values between 0.06 and 0.08. No prior knowledge of the age distribution is required. This precision range was selected since it reflects the minimum power required to detect:

i) a disappearance (or reappearance) of the “tails” (*i.e*. young and old extremities) of an age distribution (with exponentially decaying age class sizes), or

ii) a significant change in central tendency of the distribution, when such a change actually occurs.

Catch curve analysis also assumes that the population has reached equilibrium relative to a constant annual recruitment. Thus, if there has been significant recruitment variation through time then the fit may be a poor representation of the average total mortality.

6.2 Methods

Length data are routinely collected from the charter sector (2002/03 and 2005/06) and during recreational surveys (1996/97 and 2005/06). In addition, age samples are collected as part of a biological sampling programme (Table 8). The sampling program and detailed methods for estimating age are provided in St John *et al.* (2007).

Due to the high commercial value of whole pink snapper and dhufish it was not possible to take samples of whole fish at markets or processors. Therefore only legal size fish frames were obtained from the commercial wetline, longline and demersal gillnet fishers, processors, and from restaurants. Samples from the boat-based recreational fishery were collected from fishers operating individually, or as participants in fishing competitions. Undersize fish were collected by research staff and recreational and commercial fishers operating under exemptions. Although location within the region was surmised for all samples, the exact location of capture *(i.e*. GPS location) was rarely volunteered. Samples were either whole fish or filleted frames and fresh or frozen.

Table 8. The age sample sizes for dhufish, pink snapper and baldchin groper collected from each zone in the West Coast bioregion. Age samples were collected by sector in each Kalbarri, Abrolhos, Midwest, Metro offshore, Cockburn Sound and South zones. Blanks represent zones where age samples were not collected for a species.

	Sector	Kalbarri	Abrolhos	Midwest	Metro Offshore	Cockburn Sound	South
Dhufish							
2003-06	Commercial	22	92	1285	158		273
	Recreational	21	1	154	913		520
	Research	10	3	66	35		13
Pink snapper							
2003-06	Commercial	427	104	1336	74	626	116
	Recreational		1	70	602	68	148
Baldchin groper							
1993-95	Commercial		501				
2000-02	Commercial			367			

The method is based on the theory that if the fish population is experiencing both natural and fishing mortality, and there is average recruitment, the age classes should exhibit an exponentially declining relative abundance. The model is:

$$N_t = N_0 e^{-Zt}$$

where N_t is the numbers at t age and Z is the total mortality, and N_0 is the number of fish in the zero age class.

This model (Method 1) can be linearised by log-transformation:

$$\ln(N_t) = \ln(N_0) - Zt\,,$$

whose gradient represents the total mortality Z of the fish in the population and "ln" represents the natural logarithm of the value. It is common practice to omit from the regression the numbers of fish which are not fully selected and the data regression is often truncated when age class frequencies are zero, however it is possible this method may over estimate Z.

A second model (Method 2) to overcome some of these limitations involved a robust piecewise log-linear regression of relative age frequency. The method involves estimation of Z for a fixed t* using:

$$\ln(P_t) = \begin{cases} \ln(P_0 + K) - Zt & \text{when } t_{\text{median}} < t < t^* \\ \ln(K) & \text{when } t \geq t^* \end{cases}, \text{ where } P_t = \frac{N_t}{\sum N_t} \text{ and } K{=}0.005.$$

Likelihood estimation procedure involves minimisation of absolute deviation of the Laplacian error terms. Piecewise regression is optimised at t* by iterative likelihood methods. The robust nature of this method reduces the impact of large spikes in the age sample, and in some instances this is appropriate. However if the spikes are genuine then the method may underestimate Z. The smallest sample size for the indicator species in this study is considered to be 200. Thus K=0.005 was selected as proportion of the smallest unit in a sample of size 200. In this method, the estimated value of Z is highly sensitive to the value of K selected.

A third model (Method 3) estimated the numbers at age caught from the starting number at age 0, the selectivity, s_t and fishing mortality (F):

$$N_{t+1} = N_t \left(\frac{s_t F}{M + s_t F} \right) (1 - e^{-(M + s_t F)}) .$$

The selectivity function is:

$$s_t = 1/(1 + e^{\ln(19)(A50 - t)/(A95 - A50)}) ,$$

where *A50* and *A95* are the age *t* at which 50% and 95% of fish are selected respectively.

Assuming a natural mortality (*M*) is known, the estimation procedure involves a multinomial likelihood using the available data to estimate the selectivity as well as the fishing mortality (i.e. 3 parameter model). Alternatively the estimation procedure can involve lognormal errors using the available data to estimate the selectivity and the initial recruitment into the smallest age class as well as the fishing mortality (i.e. 4 parameter model).

Natural mortality was estimated using the maximum age method and linear regression for teleosts (Hoenig 1983, Hewitt and Hoenig 2005, Table 9). Both methods gave similar estimates, however the bounds from the regression method were wide.

Table 9. Natural mortality estimates (year^{-1}) using maximum age method and linear regression.

	Maximum age	*M* Maximum age method	*M* Regression method	Lower bound (Regression method)	Upper bound (Regression method)
Dhufish	41	0.11	0.12	0.04	0.30
Pink snapper	39	0.12	0.12	0.04	0.31
Baldchin groper	22	0.21	0.22	0.07	0.55

Given that the age sample has a set of age classes that are not fully selected and so exhibit a rising trend followed by fully selected age classes, this approach assumes that there is enough information in the rising side of the distribution to properly estimate the two selectivity parameters. If there are too few age classes in the rising part of the distribution, this assumption would be invalid (the model would be over-parameterized) and the estimation of the selectivity would confound the estimation of total mortality.

6.3 Results

6.3.1 Dhufish

Dhufish length samples were available from the charter sector and boat-ramp based creel surveys (Figure 73). The length data indicate that the majority of retained dhufish are legal size (>500 mm)

Adequate dhufish age samples were also collected through biological sampling in the Midwest, Metro and South zones for both the commercial and recreational sectors (Figure 74). Age samples collected between 2003 and 2006 were combined to ensure adequate samples. Sexes were combined after preliminary analyses demonstrated that *F* estimates were similar between male and female age samples.

The maximum age has dropped by 10 years from 41 years collected in samples a decade ago (1996-98, Hesp *et al*. 2002) to 31 in recent sampling (2003-06) collected by St John *et al*. (2007). In addition, the proportion of fish aged > 13 years old has declined from 24% down to only 9%. Much of the current fishery appears to be supported by four stronger year classes that recruited over the period 1993 to 1997 with little subsequent recruitment of significance.

The estimate of *F* determined from the 1996-98 age samples was 0.11 per year (Hesp *et al*. 2002, Figure 75). The parameter estimates for each method are compared in Table 10. The recruitment pulse present in the age samples indicates that the assumption that the population has reached equilibrium relative to a constant annual recruitment may not be valid. The robust piecewise log-linear regression (Method 2) and Method 1 analysis for the recreational age sample for the south zone did not provide realistic results ($F<0$).

Overall the F estimates were larger than *M* except for the age sample from the commercial sector in the metro zone. The Midwest recreational and Metro commercial sample sizes are very small (<160) and hence estimates should be treated with caution.

Table 10. The parameter estimates for Method 1 and Method 3. See methods for more details. *N* is the sample size.

Dhufish (*M*=0.11)	**Sector**	**Method 1**	**Method 3**			***N***
		F	***F***	***A*50**	***A*95**	
Midwest	Recreational	0.23	0.17	6.06	7.94	154
	Commercial	0.18	0.19	5.36	6.91	1285
Metro	Recreational	0.14	0.22	7.29	9.94	913
	Commercial	0.06	0.09	5.74	7.76	158
South	Recreational	NA	0.15	8.31	11.24	520
	Commercial	0.11	0.16	8.05	10.57	273

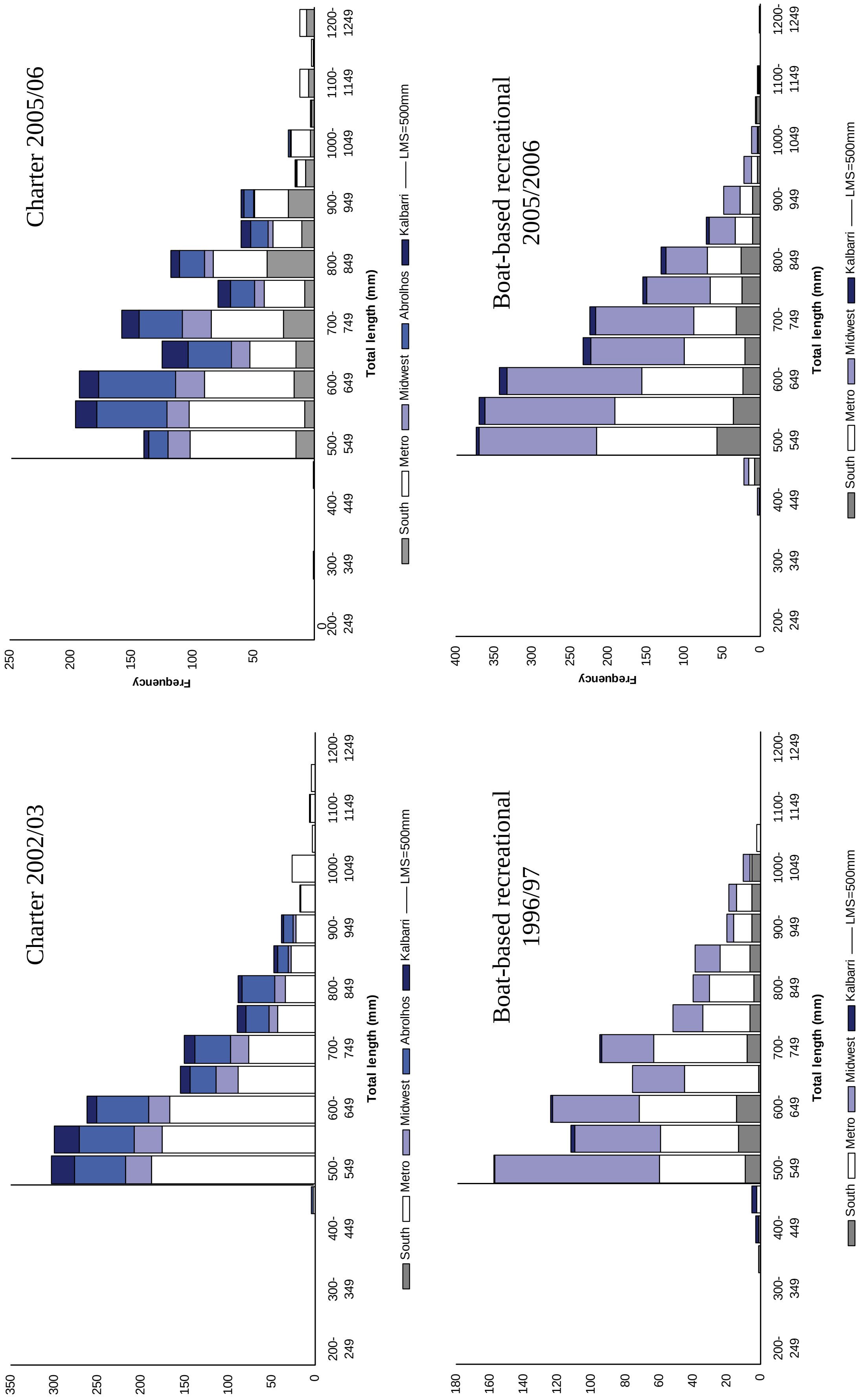


Figure 73. Dhufish length frequencies from the charter sector and boat ramp based creel surveys from Kalbarri, Abrolhos, Midwest, Metro and South zones.

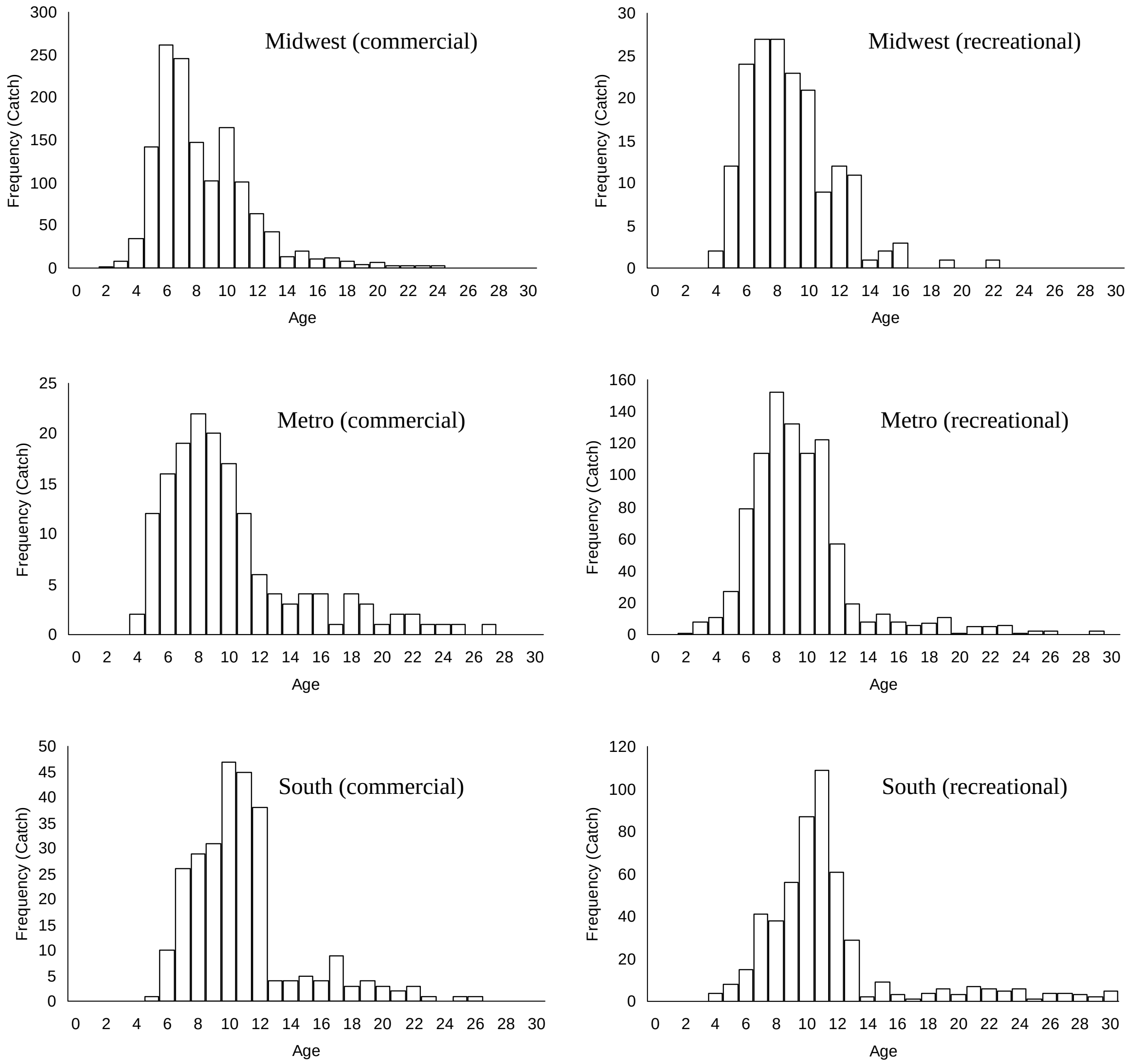


Figure 74. Commercial and recreational dhufish age samples collected between 2003 and 2006 from Midwest, Metro and South zones.

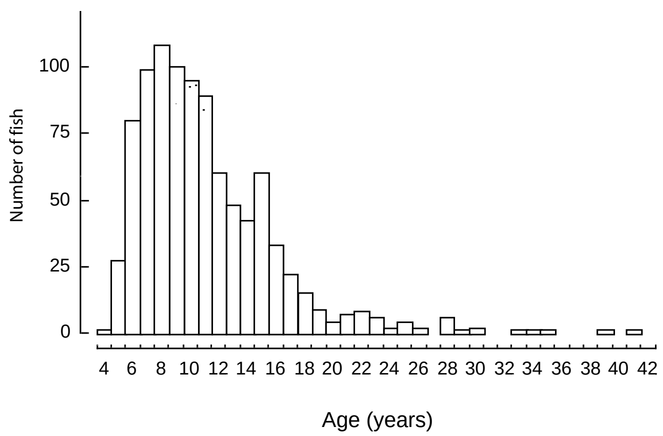


Figure 75. Commercial dhufish age samples collected from the West Coast Bioregion between 1996-98 (Hesp *et al*. 2002).

6.3.2 Pink Snapper

Pink snapper length samples were available from the charter sector and boat ramp-based creel surveys (Figure 76). The length data indicate that the majority of kept pink snapper are between 410 mm and 550 mm.

Adequate pink snapper age samples were also available through biological sampling in the Kalbarri, Midwest, Metro, Cockburn Sound and South zones from commercial and recreational sectors (Table 8, Figure 77). In the northern zones, the age samples came predominately from the commercial catch while in the Metro zone the age samples came mainly from the recreational sector. Very few age samples were collected from the south zone and consequently the data from multiple years (2003-2006) and sexes was combined to ensure adequate samples. Snapper may live to more than 30 years of age however most fish caught are under 10 years of age. In Cockburn Sound, where older and larger fish are common on the spawning grounds, they are still mostly less than 13 years of age.

The parameter estimates for each method are compared in Table 11. Since there are too few age classes in the rising part of the distribution it is not possible to estimate selectivity and hence Method 3 was not used to provide estimates of fishing mortality.

Very few fish are present in the age samples beyond age 10 except in Cockburn Sound suggesting highly depleted stocks and thus the overall F estimates were much larger than M in all zones.

Table 11. The parameter estimates for Method 1 and Method 2. See methods for more details. N is the sample size.

Pink Snapper (M=0.12)	Sector	Method 1	Method 2		N
		F	*F*	*t**	
Kalbarri	Commercial	0.80	0.47	12	427
Midwest	Commercial	0.88	0.63	10	1336
Metro	Recreational	0.76	0.60	10	602
Cockburn	Commercial	0.49	0.52	16	626
South	Recreational/ Commercial	0.37	0.27	16	264

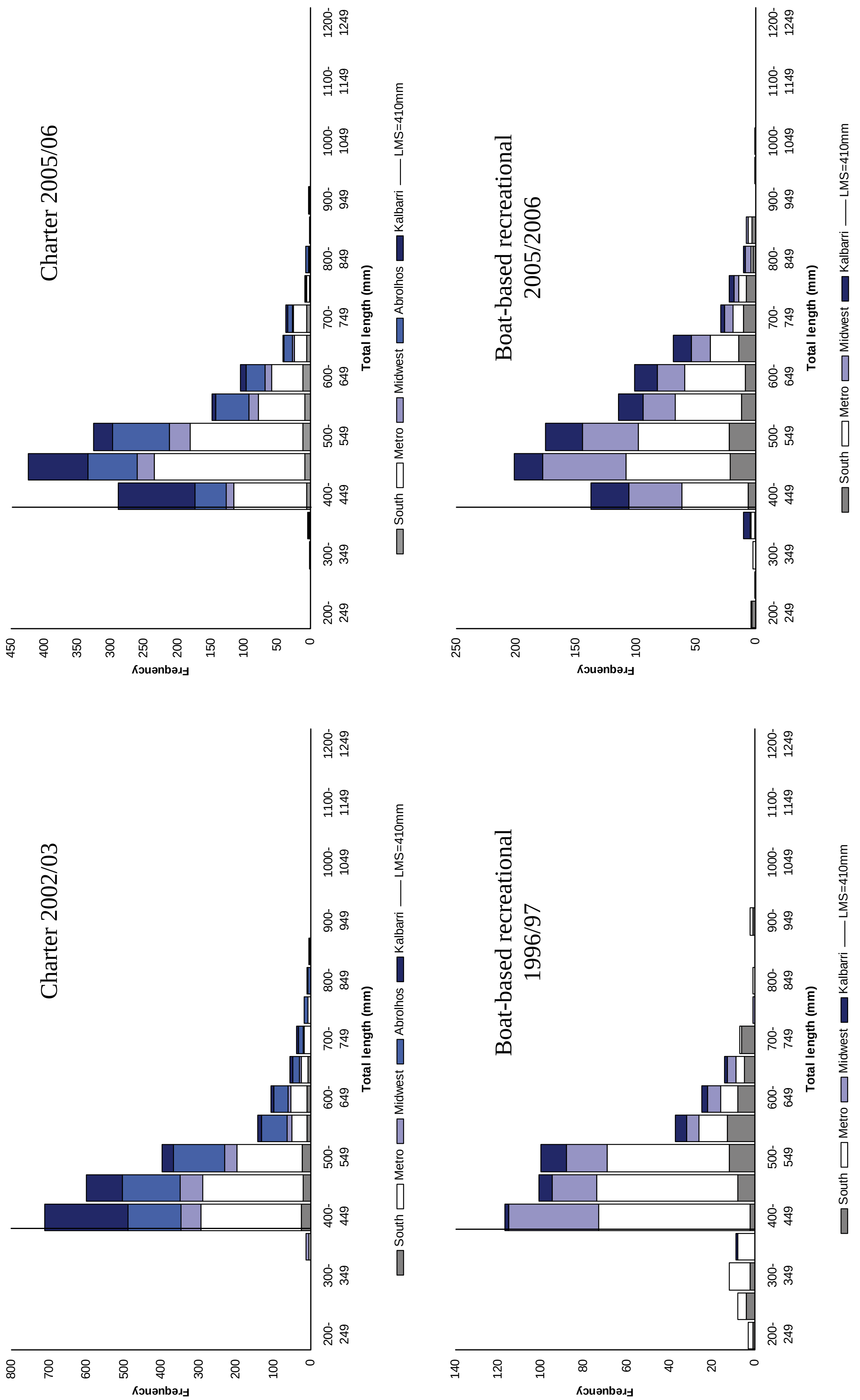


Figure 76. Pink snapper length frequencies from the charter sector and boat ramp based creel surveys from Kalbarri, Abrolhos, Midwest, Metro and South zones.

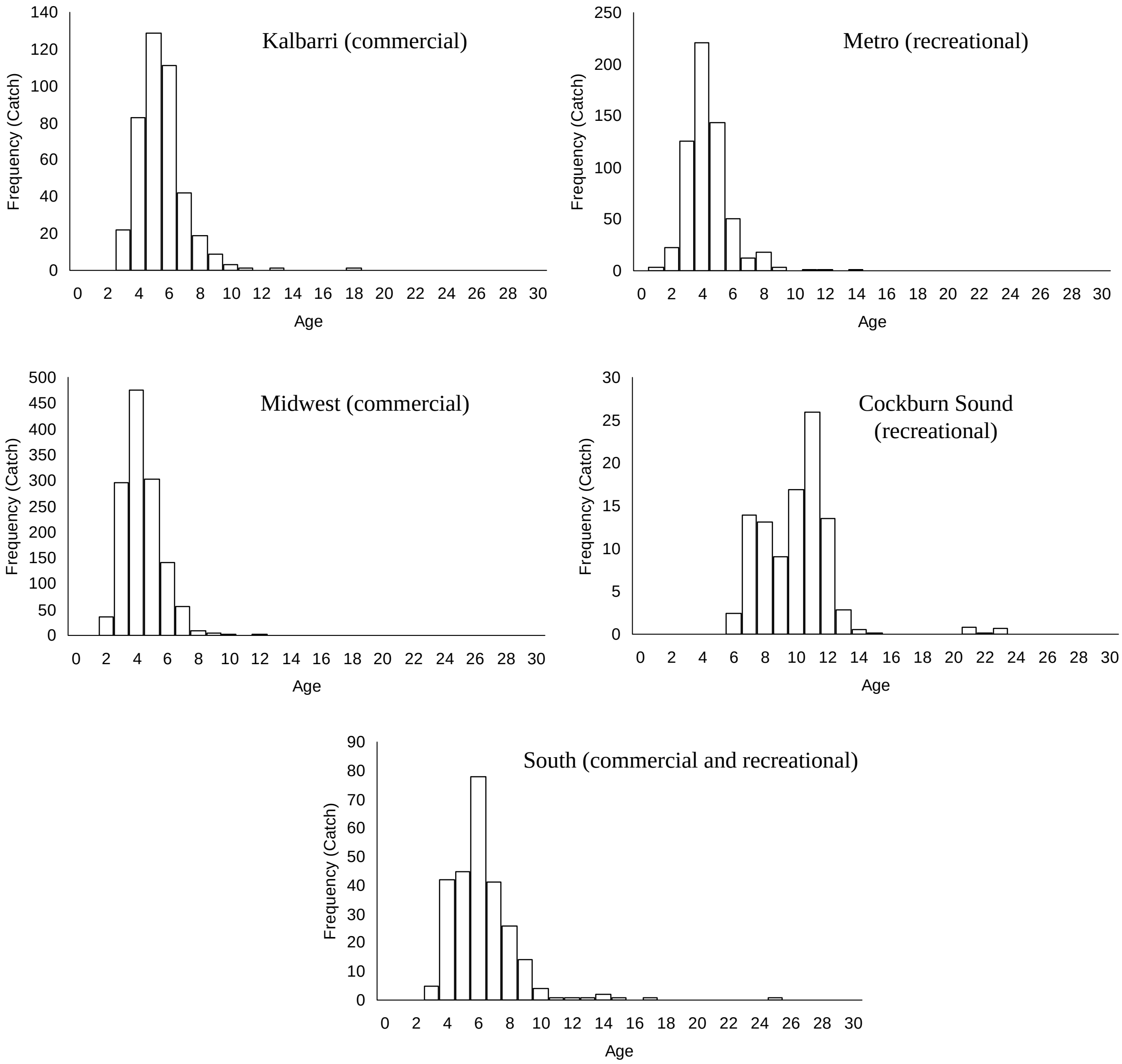


Figure 77. Commercial and recreational pink snapper age samples collected between 2003 and 2006 from Kalbarri, Midwest, Metro, Cockburn Sound and South zones.

6.3.3 Baldchin groper

Baldchin groper length samples were available from the charter sector and boat ramp based creel surveys (Figure 79). The length data indicate that the majority of retained baldchin groper are between 400 mm and 550 mm.

Baldchin groper age samples were also available through biological sampling in the Abrolhos and broader Midwest zones from the commercial sector during earlier studies (Figure 78). Age samples were combined by years and sexes to ensure adequate samples, however baldchin groper change sex from female to male between the ages of 8 and 12 years old.

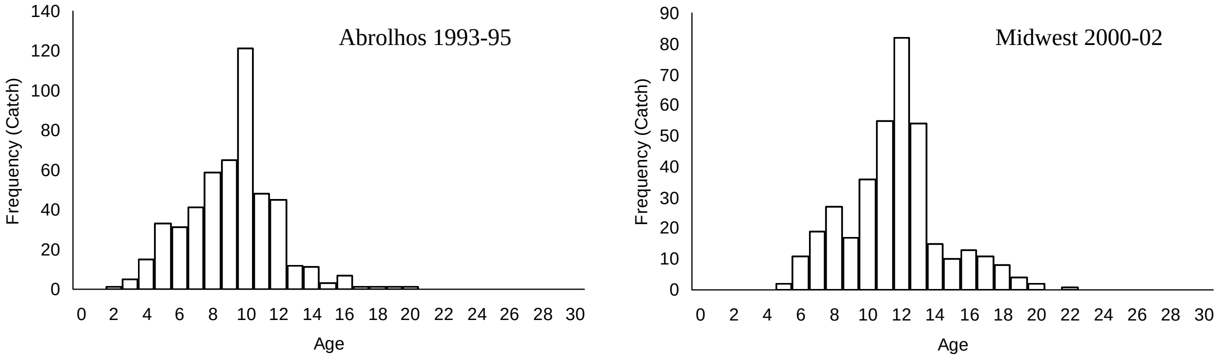


Figure 78. Baldchin groper age samples collected from the commercial sector from the Abrolhos 1993-95 and Midwest 2000-02 (Nardi *et al*. 2006 and Fairclough, 2005 respectively).

The parameter estimates for each method are compared in Table 12. Lognormal errors were used in method 3 to provide a better fit the large spike in one of the age classes compared to the multinomial likelihood. Overall the F estimates were larger than M in the Abrolhos but were lower in the broader Midwest zone.

Table 12. The parameter estimates for Method 1, Method 2 and Method 3. See methods for more details. N is the sample size.

Baldchin groper (M=0.21)	Sector	Method 1	Method 2		N	
		F	F	*t**		
Abrolhos (1993-95)	Commercial	0.28	0.12	20	501	
Midwest (2000-02)	Commercial	0.15	0.17	22	367	
		Method 3				N
		F	*A50*	*A95*	N_0	
Abrolhos (1993-95)	Commercial	0.28	8.18	11.16	5182.5	501
Midwest (2000-02)	Commercial	0.20	10.67	14.16	7011.8	367

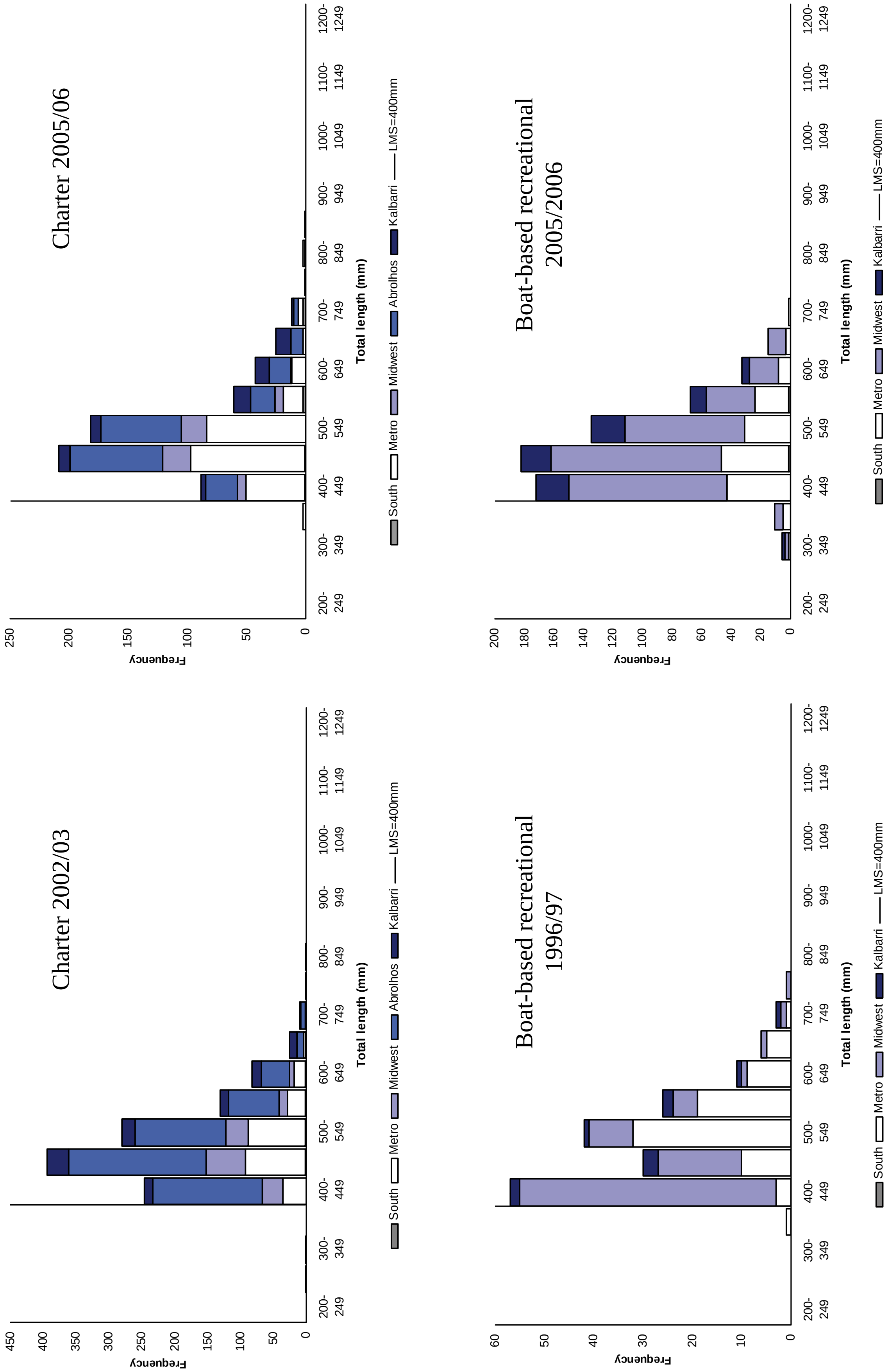


Figure 79. Baldchin groper length frequencies from the charter sector and boat ramp based creel surveys from Kalbarri, Abrolhos, Midwest, Metro and South zones.

6.4 Summary of fishing mortality relative to stock performance measures

Each method to estimate total mortality is based on differing assumptions; however the F estimates indicate similar levels of exploitation each for dhufish (Table 13), pink snapper (Table 14) and baldchin groper (Table 14). All three species show signs of currently experiencing some level of over-fishing, with F in each case except baldchin groper in the Midwest being higher than either the *limit* or *threshold* indicator levels.

Table 13. F estimates for Method 1 and Method 3. See methods for more details. Status was determined by comparing to $F_{threshold}$=M and F_{limit}=M*3/2. N is the sample size.

Dhufish (M=0.11)	**Sector**	***F* Method 1**	***F* Method 3**	**N**	**Status**
Midwest	Recreational	0.23	0.17	154	$F>F_{limit}$
	Commercial	0.18	0.19	1285	
Metro	Recreational	0.14	0.22	913	$F>F_{threshold}$
	Commercial	0.06	0.09	158	$(F>F_{limit}$*)
South	Recreational	NA	0.15	520	$F_{threshold}$ >F> F_{limit}
	Commercial	0.11	0.16	273	

* There are age samples that indicate F is actually above F_{limit} in the metro zone. NA indicates that the method was not applicable to the age sample. The Midwest recreational and Metro commercial sample sizes are very small (<160) and hence estimates were not used in determining status. Method 2 was identified as not applicable to dhufish data.

Table 14. F estimates for Method 1 and Method 2. See methods for more details. Status was determined by comparing to F_{limit}=M*3/2. N is the sample size.

Pink snapper (M=0.12)	Sector	*F* Method 1	*F* Method 2	N	Status
Kalbarri	Commercial	0.80	0.47	427	$F>F_{limit}$
Midwest	Commercial	0.88	0.63	1336	$F>F_{limit}$
Metro	Recreational	0.76	0.60	602	$F>F_{limit}$
Cockburn	Commercial	0.49	0.52	626	$F>F_{limit}$
South	Recreational/ Commercial	0.37	0.27	264	$F>F_{limit}$

Method 3 was identified as not applicable to pink snapper data.

Table 15. F estimates for Method 1, Method 2 and Method 3. See methods for more details. Status was determined by comparing to F_{target}=M*2/3, $F_{threshold}$=M and F_{limit}=M*3/2. N is the sample size. * Lognormal errors were used.

Baldchin groper (M=0.21)	Sector	*F* Method 1	*F* Method 2	*F* Method 3	N	Status
Abrolhos (1993-95)	Commercial	0.28	0.12	0.28	501	$F_{threshold}$ >F> F_{limit}
Midwest (2000-02)	Commercial	0.15	0.17	0.20	367	F_{target} >F> $F_{threshold}$

7.0 Biological information and per recruit analysis

7.1 Introduction

Quantitative information is available for dhufish, pink snapper and baldchin groper in the West Coast Bioregion. Biological information for dhufish and pink snapper are primarily from St John *et al.* (2007) while baldchin groper information is from Fairclough (2005) and Nardi *et al*. (2006). This information includes age and growth, reproduction, body size conversions. In addition there are the current management measures of size and bag limits. This information forms the basis of yield per recruit and egg per recruit analyses.

Yield per recruit and egg per recruit determine the expected equilibrium lifetime yield per fish and contribution to the spawning stock biomass per fish respectively, based on the rate of growth, maturity, natural mortality and exploitation.

Based on the available information the current status and vulnerabilities of dhufish, pink snapper and baldchin groper are presented.

7.2 Methods

All quantitative biological and life history information was collated and is presented. This information includes age and growth, reproduction, body size conversions and the current management measure of size and bag limits.

Yield per recruit (YPR) was calculated as:

$$YPR = \sum_{sexes}\sum_{t=0}^{\infty} \frac{S_{sex,t}F}{S_{sex,t}F + M}(1 - e^{-M - S_{sex,t}F})N_{sex,t}w_{sex,t} ,$$

and egg per recruit (EPR) was calculated as:

$$EPR = \sum_{t=0}^{\infty} N_{female,t} Pmat_t \, fec_t ,$$

where: N_t is the population size at age t calculated from

$$N_{sex,t+1} = N_{sex,t}(1 - Psexchange_t)e^{-M - S_t F} ,$$

M is natural mortality,
F is fishing mortality,
sex is either female or male,

$S_{sex,t}$ is fishing selectivity at age t and calculated as $S_{sex,t} = \begin{cases} 1 \text{ if } l_{sex,t} \geq LMS \\ 0 \text{ if } l_{sex,t} < LMS \end{cases}$,

LMS is the legal minimum size,
$l_{sex,t}$ is length at age t of fish based on the von Bertalanffy growth curve,
$w_{sex,t}$ is weight at age t of the fish related to fish length $l_{sex,t}$,
$Pmat_t$ is the proportion of females mature at age t related to fish length $l_{female,t}$,
fec_t is the batch fecundity at age t. $fec_t = w_{female,t}$ when fecundity is unknown,
$Psexchange_t$ is the proportion changing sex at age t related to fish length $l_{female,t}$ and $Psexchange_t = 0$ when species does not undergo sex change,
$N_{sex,0}$ is initial population and $N_{sex,0} = \begin{cases} 1 & \text{if species undergo sex change} \\ 0.5 & \text{if species does not undergo sex change} \end{cases}$.

7.3 Results

7.3.1 Dhufish

Distribution, Structure and Movement

West Australian dhufish is endemic to Western Australia ranging from Shark Bay (26°S, 113°E) in the north to Recherche Archipelago (34°S, 122°) in the south (Hutchins and Swainston 1986, McKay 1997), however, they are most abundant from the Abrolhos Islands to Cape Naturaliste.

A study of stable isotope analyses in otolith carbonates found that the trend in oxygen isotopic concentrations for dhufish followed the increase in water temperatures from south to north. Oxygen isotopic concentrations of the otolith carbonate delineated the northern dhufish to be most spatially disparate from elsewhere. Oxygen isotopes in otolith carbonates of dhufish were deposited in equilibrium with the ambient water suggesting that dhufish experience lifetime, or at least very prolonged, exposure to the unique isotopic conditions in each region. Thus, oxygen isotope analyses have shown that dhufish are lifetime residents of their particular geographical location and any movement of juveniles and adults is small scale. This result is supported by preliminary results of tagging studies by the recreational sector, that found that 90% of dhufish are recaptured in the same location, and only one fish moved more than 30 nm from its point of release (ANSA-WA data). Juveniles live in close association with rocky reefs and are not known to move.

Age and Growth

Dhufish are long lived and slow growing. Females grow more slowly than males attaining the legal minimum size of 500 mm at around 7 years, while males take 6 years (Hesp *et. al*. 2002). Despite living more than 40 years, there are presently few fish older than 13 years in the population. Compared with an earlier examination of the age structure of dhufish in the late 1990s (Hesp *et. al*. 2002), current studies have revealed that the maximum age recorded in the south of the West Coast Bioregion has decreased by 10 years from 41 years, and the proportion of dhufish older than 13 years of age has declined from 28% to 9%. In addition, males are growing significantly faster than 10 years ago, attaining larger sizes at younger ages but this density-dependent growth effect is not apparent in females.

Regional differences in age structure are evident in the West Coast Bioregion as older and larger fish are found in the south of the bioregion, whereas a higher proportiona of smaller and younger fish are found in the north of the bioregion. Although growth varies between the sexes with females growing slower than males, the age distribution of dhufish did not vary between the sexes within each region.

Reproduction

Dhufish are a gonochronistic batch spawners and the sex ratio of dhufish catches are 1:1. Hesp *et. al*. (2002) estimated size at first sexual maturity for 50 % of individuals at approximately 300 and 320 mm for female and males respectively. By the end of their third year of life, more than 50 % of both sexes have matured.

Dhufish appear to have a complex reproductive biology and hierarchical social/mating system where spawning is patchy over the relatively small spatial scale even during the peak spawning season. *Dhufish spawn* from November to March, but not all mature female dhufish appear to spawn throughout the breeding season. The amount of eggs spawned per individual and the frequency of spawning was variable among regions. Large and older females produce exponentially more eggs due to their body size and their higher frequency of spawning. As size of females varies regionally, the reproductive output of dhufish varies throughout the West Coast Bioregion. Northern females are smaller and less fecund and spawn less frequently.

An unusually large proportion of mature females undergo atresia (resorption of oocytes) during the peak spawning season (spawning females = 40% in the northern region, 60% in the Metro zone and 80% in the southern region) and ovaries in this condition were indistinguishable from those of immature females when macrostaging (upon visual inspection). The frequency of atresia decreases with the size of females.

Dhufish males grow faster than females and the exceptionally small size of the male gonads suggests that large body-size confers greater sexual advantage when breeding. The small size of the male gonads further suggests that dhufish are pair spawners. Little is known about the spawning behaviour of dhufish and spawning events appear to be dispersed throughout the species' distribution.

Recruitment

Recruitment in dhufish is highly variable. A strong recruitment pulse of dhufish consisting of four consecutive year-classes occurred 11-14 years ago, currently comprises the oldest fish in the population. Most obvious in the south, this pattern also occurs in the Metro and in the northern region. Such intermittent recruitment increases the vulnerability of fish species to over-fishing because variable recruitment often leads to considerable gaps in the age distribution of the population.

There appears to be a strong positive relationship between successful recruitment years for dhufish and salinity. The Capes Current is associated with high saline waters off the West Coast, flowing northward during the summer and autumn and coincides with the dhufish spawning season. It is suspected that dhufish larvae from the Capes Region can be transported by the Capes Current as far north as Kalbarri within 21 of the estimated 48 day larval duration. Alternatively, the Capes Current may just be associated with other environmental factors promoting high recruitment in dhufish.

As adults are sedentary and regional dhufish populations represent separate stocks, dispersal of the eggs and larvae, with the aid of oceanographic currents, appears to be the only method that populations of dhufish can mix along of the West Coast Bioregion.

Other factors influencing susceptibility to exploitation

With a high recorded mortality dhufish are very susceptible to barotrauma (21% in1-14 m to 86% >45 m) and barotrauma increases with depth. Such high mortality affects the usefulness of size and bag limits for management of this species.

Discard rates of dhufish can be high and vary between zones, particular in the recreational sector (1-37% of boat-based recreational fishing catch, 17-38% of charter catch and 21% of commercial catch). Mortality from discards need to be considered when setting catch and effort quotas for this species.

Per recruit analysis

The quantitative information used in calculating the YPR and EPR are summarized for dhufish in Table 16. Dhufish female yield per recruit and egg per recruit showed YPR_{max} was achieved at F=0.16 and 40% and 20% of unfished egg production were achieved at F=0.08 and F=0.20, respectively (Figure 80). Current F estimates are generally between the F at 40% and 20% unfished egg production.

Table 16. Biological information (Hesp et al. 2002, Hesp unpublished data, St John *et al*. (2007) and management measures for dhufish.

Dhufish		
Age and growth		
Maximum age	41 (oldest recorded age)	
von Bertalanffy curve	*Female*	*Male*
TL_∞ (mm)	982.6	1127.9
K (per year)	0.113	0.116
t_0 (years)	0.753	1.308
Reproduction		
Type	*Serial batch spawner*	
Maturity	*Female*	*Male*
TL_{50} (mm)	331.2	324.2
TL_{95} (mm)	508.8	454.0
Fecundity	Batch fecundity = $(0.0841\ TL - 10.432)^3$	
Length (mm)-weight (g)		
Female	Ln W = 2.859 Ln TL - 10.085	
Male	Ln W = 2.898 Ln TL - 10.343	
Management measures		
LML	500 mm	
Bag limit	2 per person	

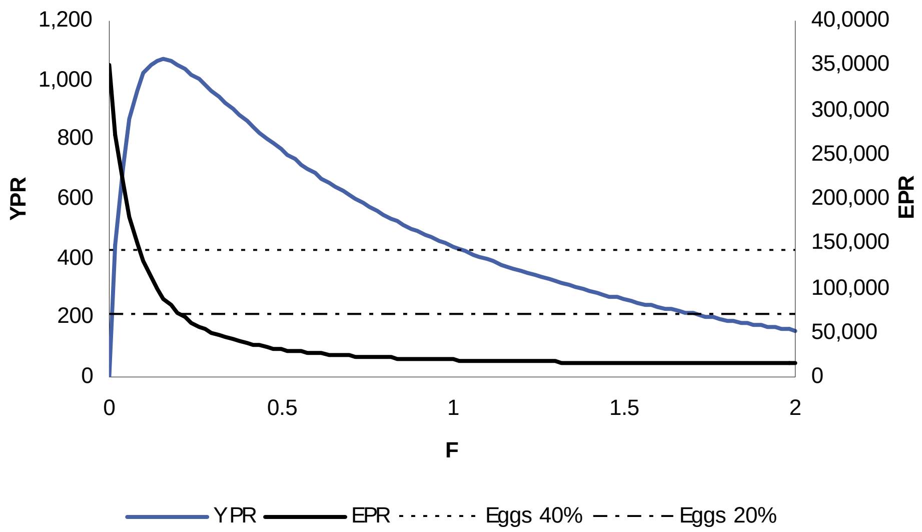


Figure 80. Yield per recruit (YPR in g/recruit) and eggs per recruit (EPR in eggs/recruit) for female dhufish.

7.3.2 Pink snapper

Distribution, Structure and Movement

In Australia pink snapper 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 up to 200 m in depth. Biological parameters vary widely among subtropical and temperate populations from various states and within Western Australia, particularly the Shark bay region where pink snapper from the Inner Shark Bay are quite distinct compared to elsewhere along the coast.

In Western Australia most of the state's commercial pink snapper catch comes from oceanic waters in the Shark Bay region and the northern area of the West Coast Bioregion (~26º S, 113º E). The two known major spawning areas along the west coast include Carnarvon and Cockburn/Warnbro Sounds. Of the two spawning sites Carnarvon is larger (100s of tonnes caught annually) and although more open oceanographically, there is no evidence of significant larval dispersal from spawning grounds. Cockburn Sound is smaller (10s of tonnes caught annually), enclosed oceanographically and also provides a nursery habitat for 0+ and 1+ fish.

There is no evidence to indicate that adult pink snapper migrate along the coast throughout the bioregion. However results of preliminary tagging studies show seasonal inshore-offshore migrations of adults in the metropolitan region to spawn in Cockburn Sound. The oxygen isotopic concentration of the otolith carbonate of pink snapper was examined from samples of fish of around 450 mm in size. Most of the pink snapper in these samples would be immature. Oxygen isotopic concentrations of the otolith carbonate in the northern region did not vary significantly from the south region suggesting that in the period prior to attaining 450 mm pink snapper from the West Coast Bioregion have intermixed throughout the bioregion.

Age and Growth

Although pink snapper are long lived (>30 years), most of the population is less than 10 years old in the West Coast Bioregion. The age frequencies were generally unimodal, dominated by ages 4-5 years in the northern region, ages 3-4 years in metropolitan offshore waters and ages 5-8 years in the southern region. In each region there was a significant absence of fish older than 10 years of age, (except for the spawning aggregation in Cockburn Sound, where the modal age class was 10-11 years). Growth of pink snapper did not vary among the sexes but the pink snapper from Cockburn Sound grew faster than pink snapper from elsewhere in the West Coast Bioregion. Legal minimum size of 410 mm was attained by age 4-7 years.

Reproduction

Pink snapper are late gonochorists or functional gonochorists (Francis and Pankhurst 1988). Pink snapper spawn in aggregations over several months and synchronise spawning on the lunar cycle. Timing and duration of spawning varies annually and depends on water temperature and environmental conditions as seasonal water temperature regulates gonad development in pink snapper (Scott and Pankhurst 1992). The timing of spawning by pink snapper in the West Coast Bioregion varies between years as it is influenced by small changes in water temperature. On the West Coast Bioregion pink snapper spawn mainly from July to October in the northern region, October to January in Cockburn Sound and December to January in the southern region.

In the West Coast Bioregion, pink snapper maturity occurs at approximately half their maximum size. There were strong regional differences in the reproductive biology of pink snapper. Size at maturity varied among regions, with half of females in the northern region reaching maturity by 490 mm compared to 580 mm in the metropolitan region. The current legal minimum size of 410 mm is below the size at maturity in all regions.

The reproductive characteristics of pink snapper populations vary depending on the presence or absence of spawning grounds. Compared to elsewhere on the West Coast Bioregion, Cockburn

Sound has a higher proportion of larger, older fish spawning fish. Pink snapper are vulnerable to fishing when spawning because their spawning aggregations are predictable in time and space, pink snapper in spawning aggregations are easy to catch, and catch rates are hyperstable (*i.e.* catch rates do not drop off at the same rate as the overall decline in fish numbers). Thus, spawning pink snapper in Cockburn Sound are very susceptible to high levels of exploitation.

Recruitment

Elsewhere in temperate Australia pink snapper populations are comprised of age classes that have originated from different regions of the coast (Hamer *et al.* 2005) and juvenile pink snapper from large recruitment years are known to migrate 1000s kms from spawning areas prior to becoming residents (Fowler *et al.* 2005).

Cockburn Sound (and including the nearby Warnbro Sound) is the only recognized location in the West Coast Bioregion that consistently has spawning aggregations of pink snapper. The eggs and larvae of pink snapper spawned in Cockburn Sound are retained within the Sound by a gyre and juveniles subsequently remain in the Sound until approximately 18 months of age before they migrate offshore.

Alongshore dispersal of pink snapper in the south may be dependent upon movement of juveniles out of Cockburn Sound and on occasions from the northern spawning aggregations off Carnarvon to the north of the West Coast Bioregion. However, there is also the possibility of further dispersal (through passive drift or active swimming of larvae) during the pelagic life-stage of pink snapper spawned elsewhere in the West Coast Bioregion. Until further studies are done on the source of recruitment of pink snapper on the west coast, each zone will be treated as if it is a separate fishable stock.

Other factors influencing susceptibility to exploitation

The most important spawning ground and nursery habitat in the West Coast Bioregion is Cockburn Sound and this environment is a highly industrial area that is already subject to high and increasing human usage. Associated environmental degradation may affect the viability of the spawning aggregations including reductions in spawning biomass, egg and larval quality and growth of juveniles as it also serves as a nursery habitat for this species. Being a sheltered embayment close to Perth, Cockburn Sound is also very accessible to fishers.

Cage experiments found that release mortality increases from an average of 4% in shallow water (5, 15 and 30 m) to 66% in deeper waters (45 and 65 m). Tagging studies, however, have found relatively high recapture rates of juveniles caught from depths around 80 m by charter boats that regularly target these schools of small pink snapper. Pink snapper are susceptible to barotrauma at depths greater than 40 m. Such high mortality questions the usefulness of size and bag limits for management of this species in depths greater than 40 m.

Discard rates of pink snapper can be high and vary between zones, particular in the recreational sector (32-48% of boat-based recreational fishing catch, 9-54% of charter catch). There is no data for the commercial fishery. Mortality from discards need to be considered when setting catch and effort quotas for this species.

Per recruit analysis

The quantitative information used in calculating the YPR and EPR is summarized for pink snapper in Table 17. Pink snapper female yield per recruit and egg per recruit show similar patterns in the North (Midwest, Abrolhos and Kalbarri combined), Metro, Cockburn Sound and

South zones. YPR_{max} ranged between F=0.14-0.18. The 40% and 20% values of unfished egg production were achieved at F=0.10 and F=0.22-0.24, respectively, for North and Cockburn Sound zones (Figure 81). No maturity curves were available for Metro and South zones and thus the egg per recruit for pink snapper in these zones were calculated using the Cockburn Sound maturity estimates (Table 17). Current F estimates are above the F at 20% unfished egg production.

Table 17. Biological information (St John *et al*. 2007, Wakefield unpublished data) and management measures for pink snapper. North is the combined Kalbarri, Abrolhos and Midwest zones.

Pink snapper				
Age and growth				
Maximum age	39 (oldest recorded age)			
Von Bertalanffy curve	North	Cockburn	Metro	South
FL_∞ (mm)	681.87	827.13	962.88	804.92
K (per year)	0.149	0.219	0.093	0.129
t_0 (years)	-1.256	-0.075	-1.404	-1.047
Reproduction				
Type	Serial batch spawning			
Maturity	North	Cockburn	Metro/South (not enough adequate samples)	
Female TL_{50} (mm)	426	487		
Female TL_{95} (mm)	629	682		
Male TL_{50} (mm)	566	585		
Male TL_{95} (mm)	730	752		
Fecundity	Not available			
Length (mm)-weight (g)	$W = 0.0000561\ FL^{2.827}$			
TL (mm)-FL (mm)	TL = 1.133 FL + 13.198			
Management measures				
LML	410 mm			
Bag limit	4 per person In Metro waters Cape Bouvard to Two Rocks daily bag of 4 with only one over 700mm in daily bag of 7 category One fish. Seasonal Closure for Cockburn and Warnbro sound 1 Oct to 10 Jan			

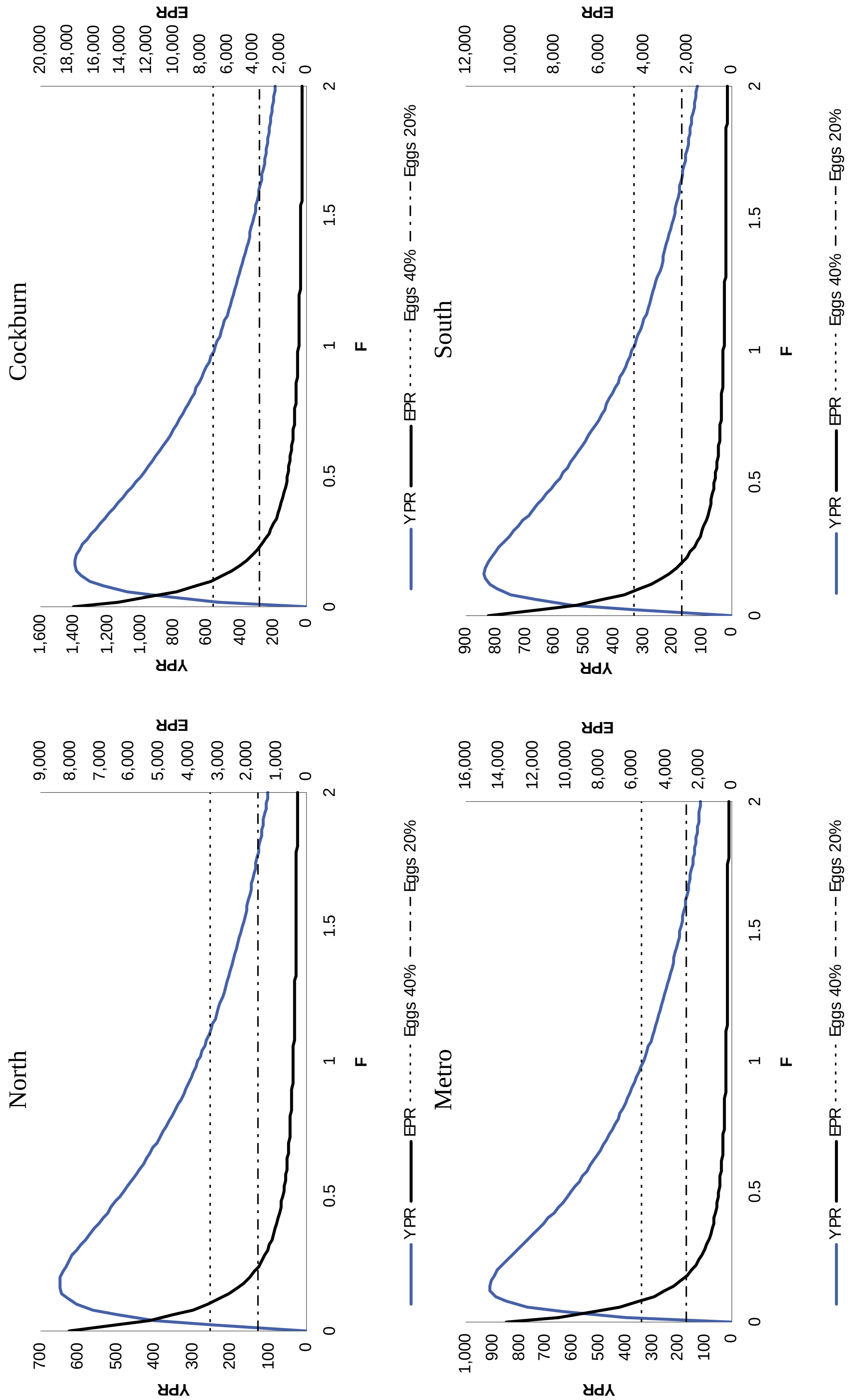


Figure 81. Yield per recruit (YPR in g/recruit) and eggs per recruit (EPR in g/recruit) for female pink snapper in the North (Kalbarri, Abrolhos, Midwest combined), Metro, Cockburn Sound and South zones.

7.3.3 Baldchin groper

Distribution, Structure and Movement

The baldchin groper is endemic to Western Australia found from Coral Bay to Cape Naturalist, being most abundant in the Abrolhos Islands region. Juveniles and adults typically occur on, or in the vicinity of, benthic reef habitat (Fairclough unpublished data). It is common in shallow (< 20 m) reef environments and commercial catches have been reported in depths down to 100 m but around the Abrolhos Islands it is typically caught down to a maximum depth of approximately 40 m. There is limited information on the movement of this species. Of the few adults that were recaptured following a research tagging and release study (13 of approximately 150 tagged and released) in the Abrolhos Islands, all were caught close (< 250 m) to their release sites (Nardi unpublished data).

Age and Growth

Baldchin groper growth is relatively gradual over the initial 8-10 years of life, prior to reaching its average maximum length (Fairclough 2005, Nardi *et al*. 2006). The maximum age reported is 22 years (Fairclough 2005).

Reproduction

Baldchin groper are born females and change sex to males from age 8 to 12 years (Nardi *et al*. 2006), with 50% of females having changed into males by 10.5 years of age and 545 mm in length (Fairclough 2005). Legal minimum size is 400 mm.

Females mature relatively early in life, with 50% of females estimated to be mature at 2.5 years old and 264 mm (Nardi et al. 2006) or 2.7 years old and 274 mm (Fairclough 2005). Baldchin groper are indeterminate batch spawners where spawning occurs over the Spring/Summer season, with peak spawning occurring from September to December in the Abrolhos Islands (Fairclough 2005, Nardi et al. 2006). Aggregations of predominantly large baldchin groper have been observed at a site in the Abrolhos Islands in December 1993 and December 1995, which demonstrated possible pre- or post-spawning behaviour and characteristics.

Recruitment

There have been no studies on the recruitment of this species.

Other factors influencing susceptibility to exploitation

There are anecdotal reports from recreational and charter fishers suggesting that baldchin groper are highly susceptible to barotrauma injuries resulting from capture by line fishing (Nardi *et al*. 2006). Preliminary results of tagging had no recaptures from 71 baldchin groper tagged over several years (ANSA-WA data). Discard rates of baldchin groper can be high and vary between zones, particular in the recreational sector (10-22% of boat-based recreational fishing catch and 10-38% of charter catch excluding south zone). There is no data for the commercial fishery. Mortality from discards need to be considered when setting catch and effort quotas for this species.

Per recruit analysis

The quantitative information used to calculate YRP and EPR are summarized for baldchin groper in Table 18. Baldchin groper yield per recruit and egg per recruit were calculated for combined Midwest and Abrolhos zones where YPR_{max} was achieved at F=0.3 and 40% and

20% of unfished egg production was achieved at F>1.0 (Figure 82). It should be noted that while the egg per recruit relationship suggests that with the current LMS, it would be difficult to over-fish the female population, because the species changes sex, however the older/larger males are highly vulnerable to fishing.

Table 18. Biological information (Fairclough, 2005 and Nardi *et al*. 2006) and management measures for baldchin groper.

Baldchin groper		
Age and growth		
Maximum age	22 (oldest recorded age)	
Von Bertalanffy curve	Fairclough (2005)	Nardi *et al*.(2006)
TL_{∞} (mm)	534.7	498.4
K (per year)	0.192	0.259
t_0 (years)	-0.162	-0.456
Reproduction		
Type	Batch spawner	
Maturity	Fairclough (2005)	Nardi *et al*. (2006)
Female TL_{50} (mm)	279.0	264 .0
Female TL_{95} (mm)	352.3	
Sex change to males	Fairclough (2005)	
TL_{50} (mm)	478.9	
TL_{95} (mm)	594.7	
Fecundity (Fairclough 2005)	Mean batch fecundity (BF) 41,635 eggs (n=27; mean TL=383 mm; mean weight=1324 g) BF = 5.05 Ln TL – 19.61	
Length (mm)-weight (g)	W = 3.024 Ln TL – 10.891 (Fairclough 2005) W = 0.000013 TL $e^{(3.139)}$ (Nardi *et al.* 2006)	
Management measures		
LML	400 mm	
Bag limit	4 per person	

Note: Fairclough (2005) sampled broader Midwest zone while Nardi *et al*. (1996) samples were from the Abrolhos.

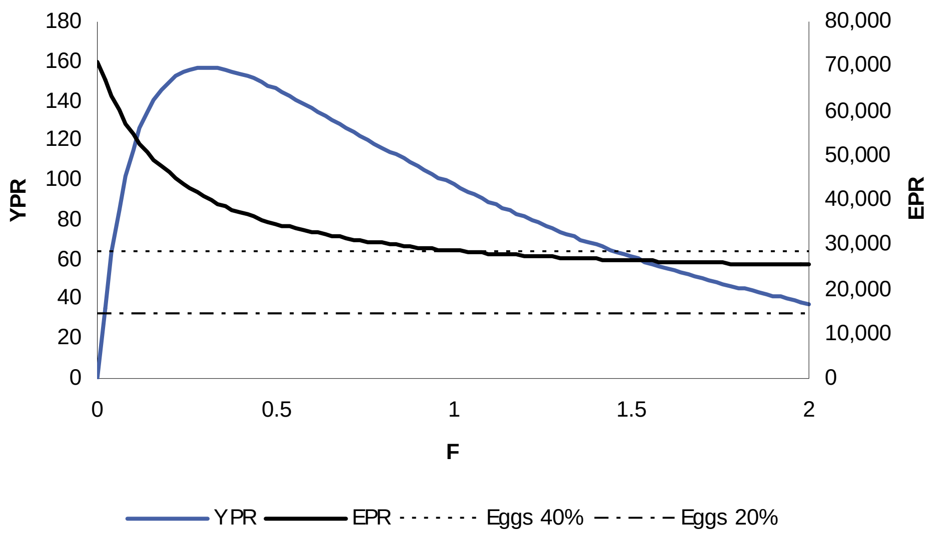


Figure 82. Yield per recruit (YPR in g/recruit) and eggs per recruit (EPR in eggs/recruit) for female baldchin groper in the combined Midwest and Abrolhos zones.

7.4 Discussion

Dhufish, pink snapper and baldchin groper are highly vulnerable to over-fishing and all three species show signs of currently experiencing some level of over-fishing.

Available information from the above sections were collated and are presented to show the current status and vulnerabilities of dhufish, pink snapper and baldchin groper. This information includes distribution and movement of adults, growth, natural mortality, reproduction mode, spawning behaviour, recruitment/replenishment of stocks, age/length distributions, effort/catch and resilience of the species to anthropogenic and/or environmental change. Current status and vulnerabilities are summarized for dhufish (Table 19), pink snapper (Tables 20 and 21) and baldchin groper (Table 22).

Table 19. Summary of current dhufish status and vulnerabilities.

Distribution and movement of adults	Restricted distribution, endemic and sedentary (longshore movement restricted)
Growth, Natural mortality	Long life span and slow growth, low M
Reproduction mode, spawning behaviour	Complex mode of reproduction and complex spawning behaviour – e.g. pair spawning, mode of reproduction not fully understood, suspected to form spawning aggregations of unknown size, location and timing, however aggregations when they occur are highly catchable.
Recruitment/ Replenishment of stocks	Infrequent, highly variable recruitment over time that cannot be predicted (annual range 0-100%), dispersal is limited to pelagic phase only
Age/Length distributions	Incomplete, discontinuous age/length distributions with missing age classes, particularly of older fish, and high release mortality, $F>F_{threshold}$ or $F>F_{limit}$
Effort/Catch	Effort levels are high, latent effort is high, fleet is highly mobile and has capacity for significant change in gear technology, catch levels are above previous average levels
Resilience to capture and release	Poor, suffers from acute barotrauma.
Resilience of the species anthropogenic and/or environmental change	Limited adaptability to environmental change
Recovery prospects following depletion	Likely to be low due to sporadic recruitment success.
Status	Overfishing is occurring in South zones and Severe overfishing is occurring in Midwest zone and possibly in the Metro zone
Inherent Vulnerability	High

Table 20. Summary of current pink snapper (excluding Cockburn Sound) status and vulnerabilities.

Distribution and movement of adults	Longshore movement restricted, inshore-offshore movements only
Growth, Natural mortality	Long life span and slow growth, low M
Reproduction mode, spawning behaviour	Spawning behaviour less understood, restricted spawning period and known to form spawning aggregations but size and location not well described so not predictable in time and space, however they are highly catchable. No information on survival of pelagic life-stage through to juveniles
Recruitment/Replenishment of stocks	Average recruitment is consistent but with some longer term cycles over medium time periods (e.g. 8 years, annual range ~50%), and propagules have unknown dispersal capacity during pelagic phase or juvenile stage. No known spawning aggregations within these regions
Age/Length distributions	Incomplete, discontinuous age/length distributions (missing age classes, particularly of older fish), $F>F_{limit}$
Effort/Catch	Effort levels are high and latent effort is high, fleet is highly mobile, capacity for significant change in gear technology and catch levels change from previous average levels – either increasing or decreasing
Resilience to capture and release	Good in shallow water (<40 m). Poor in deep water.
Recovery prospects following depletion	Good. Other stocks of pink snapper that have been overfished have rebounded when fishing mortality has been reduced.
Resilience of the species anthropogenic and/or environmental change	Highly adaptable to variable environments and environments/habitats are healthy and in an optimum condition
Status	Severe overfishing is occurring in all zones
Inherent Vulnerability	Medium - Low

Table 21. Summary of current Cockburn Sound pink snapper status and vulnerabilities.

Distribution and movement of adults	Mixing between Cockburn Sound and offshore Metro but proportion of mixing is unknown
Growth, Natural mortality	Long life span and slow growth, low M
Reproduction mode, spawning behaviour	Complex spawning behaviour, restricted spawning period and known to form large, predictable spawning aggregations in time and space that are highly catchable.
Recruitment/Replenishment of stocks	Regular, or consistent recruitment that is predictable on an annual basis (annual range ~20%), and propagules widely dispersed (100s of kms) during juvenile stage (possibly)
Age/Length distributions	Somewhat continuous age/length distributions (few missing age classes) $F>F_{limit}$
Effort/Catch	Effort fluctuates over time within known bounds, little latent effort, some capacity for improvements in gear technology, catches fluctuate over time within known bounds
Resilience to capture and release	Good.
Resilience of the species anthropogenic and/or environmental change	Environments/habitats are degraded and/or under threat
Recovery prospects following depletion	Good. Other stocks of pink snapper that have been overfished have rebounded when fishing mortality has been reduced.
Status	Severe overfishing is occurring
Inherent Vulnerability	High – due this region having the only known spawning aggregation in the West Coast Bioregion.

Table 22. Summary of current baldchin groper status and vulnerabilities.

Distribution and movement of adults	Restricted distribution, endemic and sedentary (longshore movement restricted)
Growth, Natural mortality	Intermediate lifespan, moderate M
Reproduction mode, spawning behaviour	Complex mode of reproduction (i.e. change sex), mode of reproduction not known or not well described
Recruitment/Replenishment of stocks	Unknown
Age/Length distributions	Somewhat continuous age/length distributions (few missing age classes), and/or low release mortality, $F>F_{threshold}$ around Abrolhos
Effort/Catch	Effort fluctuates over time within known bounds, little latent effort, some capacity for improvements in gear technology, catches fluctuate over time within known bounds
Resilience to capture and release	Low, anecdotal evidence indicates susceptibility to acute barotrauma
Resilience of the species anthropogenic and/or environmental change	Limited adaptability to environmental change
Recovery prospects following depletion	Unknown.
Status	Over-fishing is occurring around Abrolhos
Inherent Vulnerability	Medium - High

8.0 Management Implications

8.1 Introduction

Management implications for the utilization of fisheries resources are usually based on outcomes of stock assessments that characterize the status of a stock with respect to a set of performance measures (Table 1). These performance measures are based around exploitable or spawning stock biomass, and/or fishing mortality/exploitation rate, but if nothing else is available then some index of relative abundance could be used.

Through the use of the indicator species, dhufish, pink snapper and baldchin groper, the assessment task for the West Coast Demersal Scalefish Fishery becomes one of assessing whether the fisheries for these species can be considered to be sustainable at current levels of catch. Without an extended time series of good quality fisheries data the use of formal mathematical stock assessment models was not a viable option and hence the assessment was based primarily on the age frequency data and the estimation of fishing mortality.

Given that the performance measure involves fishing mortality rate, it is necessary to define reference points (Figure 2). These reference points consist of a target reference point, which is deemed an acceptable and desirable state for the fishery to achieve, a limit reference point, beyond which the fishery should not go, which if reached requires a strict management response, such as closing the fishery and a threshold reference point beyond which catches are restricted to an increasing degree until the limit reference point is reached. The suggested reference points for fishing mortality are presented in Table 1 and are typical of international practice (Caddy and Mahon 1998, Lembo 2006 and Walters and Martell 2002). The Department of Fisheries, Western Australia views these as the most appropriate performance measures, based on the biology of the species concerned.

Aiming for a target fishing mortality is more robust to uncertainty than aiming for a target biomass. If the fishing mortality estimated to be sustainable is too high it does not necessarily imply urgent or critical damage to the stock (Table 23). The certainty (or probability) that B is usually within each of the bounds is 80-90%. The probability that F is within each of the bounds is 50% (mean estimate). Moreover because the fishing mortality rate relates to a proportion of available biomass rather than an absolute mass of catch, fisheries are often more resilient to errors in fishing mortality estimates than they are to catch errors.

Table 23. The management action resulting from indicator levels of biomass and fishing pressure

		Fishing Mortality (F)			
		$F<F_{target}$	$F_{target}<F<F_{threshold}$	$F_{threshold}<F<F_{limit}$	$F>F_{limit}$
Biomass (B)	$B>B_{target}$	Sustainable	Monitor closely	Restrict fishing	Very restricted fishing
	$B_{target}>B>B_{threshold}$	Monitor closely	Monitor closely	Restrict fishing	Very restricted fishing
	$B_{threshold}>B>B_{limit}$	Restrict fishing	Restrict fishing	Restrict fishing	Very restricted fishing
	$B<B_{limit}$	Close	Close	Close	Close

Given that biomass estimates will not be available for a few years (depending on future research and monitoring) for dhufish, pink snapper and baldchin groper it is necessary to develop decision rules that operate solely on fishing mortality estimates.

8.2 Decision rules

Fisheries should have an unambiguous (explicit and quantitative) harvest strategy for the exploitation of the fish resources. It states how the catch or effort will be adjusted from year to year, depending on the size of the stock, the economic or social conditions of the fishery, conditions of other interdependent stocks, and the uncertainty regarding the biological knowledge of the stock. The strategy should indicate the data requirements and the assessment approaches to be used. Without a harvest strategy, management decisions tend to be ad hoc.

The harvest strategy should be robust to the unpredictable biological fluctuations to which the stock may be subject. It should also incorporate, explicitly, decisions about trade-offs between constant average yield and year-to-year variability in yield; and decisions about how to deal with uncertainty in stock assessments. The more stable and predictable a fishery, the longer the life of a harvest strategy can be (5–10 years) before it is reviewed and updated. However, a strategy for a newly developing fishery can be difficult to formulate and may need updating every year. Workable decision rules based on a target, threshold, and limit reference points for fishing mortality performance measure have been developed (Table 24).

Table 24. Workable decision rules based on a target, threshold, and limit reference points for each performance measure.

Biomass estimates are available for each species	Provides for a decision rule of resource biomass and fishing pressure
$B>B_{target}$	Fishing effort (and/or catches) may increase
$B_{target}>B>B_{threshold}$	Fishing effort (and/or catches) to remain constant
$B_{threshold}>B>B_{limit}$	Fishing effort (and catches) reduced to enable resource to rebuild to B_{target} based on calculated F required to rebuild stock in specified number of years.
$B<B_{limit}$	Fishery closed and resource monitored (fishery independent) until rebuilt to B_{target}

Fishing mortality (F) estimates are available but no biomass estimates	Provides for a decision rule of fishing pressure
$F<F_{target}$	Fishing effort (and/or catches) may increase
$F_{target}<F<F_{threshold}$	Fishing effort (and/or catches) to remain constant
$F_{threshold}<F<F_{limit}$	*Fishing effort (and/or catches) reduced eg 10%-50%
$F>F_{limit}$	*Fishing effort (and/or catches) reduced eg 50%-100%

* Refinement of decision rules for $F_{threshold}<F<F_{limit}$ and $F>F_{limit}$ are presented below

Catch rate and/or catch estimates are available but no biomass or fishing mortality estimates	Provides for a decision rule when minimal management is available
Within the range of the previous 5-10 years	Fishing effort (and/or catches) to remain constant
Outside the range of the previous 5-10 years	If threshold is reached management and research programs are initiated to provide estimates of biomass estimates and/or fishing mortality

The refinement of decision rules for $F_{threshold}<F<F_{limit}$ and $F>F_{limit}$ are based on the vulnerability and status of the stock (Table 25). The percentage level of reduction can be applied directly to a reduction in catch and/or effort depending on the regulatory tools implemented in the fishery. This assumes that the percentage reduction in catch and/or effort will result in a consistent reduction in fishing mortality (F). However, it should be noted that there needs to be an adaptive management approach to determine if the desired reduction in catch and/or effort leads to the desired reduction in the level of fishing mortality (F).

Table 25. Decision rules to define the percentage level of reduction of fishing pressure when estimates of fishing mortality lie in the following areas are $F_{threshold}<F<F_{limit}$ and $F>F_{limit}$ only fishing mortality estimates are available are based on low, medium and high reduction definitions.

	Low reduction	**Medium reduction**	**High reduction**
Distribution and movement of adults	Widespread distribution, and/or highly mobile (capacity to move 100s of kms along coastline)	Limited distribution, and/or limited mobility (10s of kms along coastline)	Restricted/endemic, and/or sedentary (longshore movement restricted), possibly inshore-offshore movements only
Growth, Natural mortality	Short life span (up to 10 years), or rapid growth, high M	Intermediate lifespan (10 to 20 years), or variable growth, moderate M	Long life span (> 20 years) or slow growth, low M
Reproduction mode, spawning behaviour	Straightforward gonochoristic mode of reproduction, and/or extended spawning period, and/or reproductive biology well described, and/or not known to form spawning aggregations.	Mode of somewhat complex (e.g. pre-maturational sex change), and/or limited spawning period, and/or reproductive biology known to some extent, and/or known to form spawning aggregations that are not predictable in time and space, but are highly catchable.	Complex mode of reproduction (i.e. hermaphroditic – change sex), or complex spawning behaviour – e.g. pair spawning, and/or restricted spawning period, and/or mode of reproduction not known or not well described, and/or known to form large, predictable spawning aggregations in time and space that are highly catchable.
Recruitment/ Replenishment of stocks	Regular, or consistent recruitment that is predictable on an annual basis (annual range ~20%), and/or propagules widely dispersed (100s of kms) during pelagic phase or juvenile stage	Average recruitment is consistent but variable among years over short time periods (e.g. 3 years, annual range ~50%), and/or propagules have limited dispersed capacity (10s of kms) during pelagic phase or juvenile stage	Infrequent, highly variable recruitment over time that cannot be predicted (annual range 0-100%), and/or propagule dispersal is restricted during pelagic phase and also restricted movement in the juvenile stage
Recovery prospects following depletion	Good, documented examples where this has occurred	Moderate.	Poor, recruitment dynamics and other factors suggest it may take sometime for recovery to occur.
Resilience of the species anthropogenic and/or environmental change	Highly adaptable to variable environments (e.g. pink snapper), and/or environments/habitats are healthy and in an optimum condition	Moderate levels of resilience, and/or environments/habitats are not in an optimum condition but are recovering	Limited adaptability to environmental change (e.g. dhufish -physiologically not suitable for aquaculture), and/or environments/habitats are degraded and/or under threat

Note: Refinement of decision rules is the same for $F_{threshold}<F<F_{limit}$ and $F>F_{limit}$ categories however the actual percentage reduction differs based on Table 24.

8.3 Weight-of-evidence status for the indicator species

The following tables provide full summaries of the current knowledge regarding the risk status of dhufish (Table 26), pink snapper (Table 27) and baldchin groper (Table 28). The stock assessments have indicated a need for management intervention for these key species. The information contained in these tables provide the basis for managers to determine what levels of catch/effort reduction are appropriate, which in turn will allow unambiguous consideration of how such reductions might be achieved (which is beyond the scope of this report to consider).

Table 26. Summary risk status of dhufish.

Midwest	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Reproduction mode, spawning behaviour			✓
Recruitment/Replenishment of stocks			✓
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)			✓
Effort/Catch			✓
Recovery from depletion			✓
Resilience of the species anthropogenic and/or environmental change			✓
Metro	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Reproduction mode, spawning behaviour			✓
Recruitment/Replenishment of stocks			✓
Age/Length distributions (Fishing mortality estimates where $F>F_{threshold}$ and $F>F_{limit}$*)			✓
Effort/Catch			✓
Recovery from depletion			✓
Resilience of the species anthropogenic and/or environmental change			✓
South	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Reproduction mode, spawning behaviour			✓
Recruitment/Replenishment of stocks			✓
Age/Length distributions (Fishing mortality estimates where $F>F_{threshold}$)		✓	
Effort/Catch		✓	
Recovery from depletion		✓	
Resilience of the species anthropogenic and/or environmental change			✓

* There are age samples that indicate F is actually above F_{limit} in the metro zone.

Table 27. Summary risk status of pink snapper.

Kalbarri	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Local Spawning Aggregations	✓		
Recruitment/Replenishment of stocks	✓		
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)			✓
Effort/Catch			✓
Recovery prospects following depletion	✓		
Resilience of the species anthropogenic and/or environmental change	✓		
Midwest	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Local Spawning Aggregations	✓		
Recruitment/Replenishment of stocks	✓		
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)			✓
Effort/Catch			✓
Recovery prospects following depletion	✓		
Resilience of the species anthropogenic and/or environmental change	✓		
Metro (excluding Cockburn Sound)	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Local Spawning Aggregations	✓		
Recruitment/Replenishment of stocks		✓	
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)			✓
Effort/Catch			✓
Recovery prospects following depletion	✓		
Resilience of the species anthropogenic and/or environmental change			✓
Cockburn Sound	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Local Spawning Aggregations			✓
Recruitment/Replenishment of stocks			✓
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)		✓	
Effort/Catch		✓	
Recovery prospects following depletion		✓	
Resilience of the species anthropogenic and/or environmental change			✓
South	**Low**	**Medium**	**High**
Distribution and movement of adults			✓
Growth, Natural mortality			✓
Local Spawning Aggregations	✓		
Recruitment/Replenishment of stocks		✓	
Age/Length distributions (Fishing mortality estimates where $F>F_{limit}$)			✓
Effort/Catch			✓
Recovery prospects following depletion	✓		
Resilience of the species anthropogenic and/or environmental change	✓		

Table 28. Summary risk status of baldchin groper.

Abrolhos	Low	Medium	High
Distribution and movement of adults			✓
Growth, Natural mortality		✓	
Reproduction mode, spawning behaviour			✓
Recruitment/Replenishment of stocks		✓	
Age/Length distributions (Fishing mortality estimates where $F>F_{threshold}$)		✓	
Effort/Catch		✓	
Recovery prospects following depletion		✓	
Resilience of the species anthropogenic and/or environmental change			✓

8.4 Discussion

8.4.1 Dhufish

The levels of fishing mortality for dhufish are above international benchmarks in all three zones (Table 29). Thus, fishing mortality for dhufish in the Metro zone is above the threshold and very close to the limit reference point, while in the Midwest zone levels of fishing mortality are above the limit reference point. In the south region the estimate of fishing mortality is between the threshold and the limit reference point. Integrating these results against the background of the biological attributes of dhufish indicates that the overall level of fishing effort and catch of dhufish in the West Coast Bioregion needs to be reduced by at least 50%.

8.4.2 Pink snapper

The levels of fishing mortality for pink snapper are above international benchmark standards within all zones of the west coast bioregion (Table 29). Integrating these results with the biological attributes of pink snapper suggests there needs to be a high reduction in the overall level of fishing effort and catch in the West Coast Bioregion of at least 50%, but with a complete closure to all pink snapper fishing within Cockburn Sound given that this zone has the only known major spawning aggregation in the West Coast Bioregion.

8.4.3 Baldchin groper

The examination of the available data for baldchin groper reveals that levels of fishing mortality across the entire West Coast Bioregion are between target and threshold benchmarks (Table 29). However, the level of fishing mortality for baldchin groper at the Abrolhos Islands is above the threshold benchmark indicating that localised overfishing is occurring and that management action for this species needs to be targeted at the scale of the Abrolhos Islands.

8.4.4 General

The assessments of the status of the key demersal finfish stocks in the West Coast Bioregion have undergone external peer review (Appendix 1) with the methods considered best practise for the circumstances and the conclusions considered valid and appropriate.

There remains, however, a level of uncertainty with regard to the precise status of the stocks of dhufish, pink snapper and baldchin groper due to the nature of the data and the resultant assessments. The data do not allow the proportion of the unfished or remaining breeding stock biomass to be determined. Without a precise stock biomass model, it is not possible to generate precise estimates of the level of reduction in catch/effort needed to achieve acceptable stock levels. Instead, the data and methods available here can only provide a guide to the level of effort/catch reductions that should achieve sufficient reductions in the level of fishing mortality to generate acceptable stock recoveries. Nonetheless the assessments clearly indicate that the level of fishing mortality for both species are well above international standards for sustainable exploitation and that significant overfishing is occurring.

Table 29. Summary of species-specific F estimates and commensurate reductions based on decision rules for each location in the West Coast bioregion. Note the level of reduction within the spectrum defined by the level of fishing mortality is based on the biological characteristics of the species under consideration (Refer to Tables 23-28). O = offshore, CS = Cockburn Sound.

Dhufish			
Location	**Estimate of F**	**Decision rule**	**Relative level of reduction within the range**
Midwest	$F>F_{limit}$	Fishing effort reduced by 50%-100%	High
Metro	$F_{threshold}<F<F_{limit}$[1]	Fishing effort reduced by 10%-50%	High
South	$F_{threshold}<F<F_{limit}$	Fishing effort reduced by 10%-50%	Medium - High
Pink snapper			
Location	**Estimate of F**	**Decision rule**	**Relative level of reduction within the range**
Kalbarri	$F>F_{limit}$	Fishing effort reduced by 50%-100%	Medium - Low
Midwest	$F>F_{limit}$	Fishing effort reduced by 50%-100%	Medium - Low
Metro - O	$F>F_{limit}$	Fishing effort reduced by 50%-100%	Medium - Low
Metro - CS	$F>F_{limit}$	Fishing effort reduced by 50%-100%	High
South	$F>F_{limit}$	Fishing effort reduced by 50%-100%	Medium - Low
Baldchin Groper			
Location	**Estimate of F**	**Decision rule**	**Relative level of reduction within the range**
Overall	$F_{target}<F<F_{threshold}$[2]	Fishing effort may increase	n/a
Abrolhos	$F_{threshold}<F<F_{limit}$	Fishing effort reduced by 10%-50%	Medium - High

[1] The estimate of F is very close to the limit reference point (i.e. at the upper end).

[2] When the estimate of F is between the target and the threshold reference point rigorous monitoring is required.

8.5 Implications

To address the overfishing situation, significant and comprehensive management actions will be required. Major reductions in both fishing effort and catches of these resources will be needed to reduce the rates of fishing mortality to acceptable levels. Moreover, a holistic approach to the management of these resources will be needed to effectively deal with the implications of the complex biological attributes of these species and the multi-species and overlapping nature of the various commercial and recreational fisheries involved.

There is an inherent high risk in leaving any sector of commercial and recreational fisheries unmanaged because all fishing sectors currently involved in the exploitation of these resources are capable of exerting considerable impacts on these stocks. Consequently, comprehensive and effective management restrictions/limitations of all sectors are required to have a reasonable chance of initiating recovery. Levels of effort and catch across the entire fishery need to be reduced by at least 50%. Any reduction in effort and/or catch (including a complete closure), however, may not result in a recovery of this species in the short term due to the inconsistent nature of dhufish recruitment. Therefore, the most appropriate strategy is to adopt an adaptive approach to determine if the initial reduction in effort and/or catch is at least achieving the desired reduction in the level of fishing mortality.

Furthermore, the restrictions in effort and/or catch for each sector must encompass all key indicator species and consider their biological attributes. For example any measures that rely on the increased use of releasing captured fish (e.g. tags; changes to minimum legal sizes, changes to bag/boat limits) are inappropriate for dhufish and pink snapper in deeper waters. Hence, for dhufish the primary goal for all sectors must be limit the total numbers of dhufish and pink snapper that are captured.

As part of the management plan there is an obligation for on-going monitoring of the key indicator species in the West Coast Bioregion to evaluate whether the management package that is implemented is resulting in the required level of reductions in fishing mortality. Although it is likely to take three to five years before a robust evaluation could determine whether the package has been successful, a suitably designed sampling program during this period should be able to monitor dhufish recruitment. If the recent lack of dhufish recruitment continues, then an earlier reassessment of the package will be required. This additional monitoring will require a significant level of additional funding.

8.6 Recommendations

1. The need to develop and implement an effective management package to address the current high fishing mortalities for stocks of pink snapper and dhufish in the West Coast Bioregion (and for baldchin groper at the Abrolhos Islands) is a priority.

2. The recommended management goal should be to reduce the total effort and catch of these key species across all sectors by at least 50% but with a complete closure to pink snapper fishing within Cockburn Sound.

3. The management package will need to be holistic and capable of limiting the catch and effort of all relevant recreational and commercial sectors. Any sectoral management arrangements must consider the impact of relevant biological attributes of pink snapper and dhufish on their efficacy in reducing total mortality.

4. The impacts of the reductions in effort/catch across the fishery need to be carefully monitored to evaluate whether the management package has produced the necessary reductions in sector specific catch and effort. Furthermore, the recruitment levels to the stocks will also need to be monitored on an annual basis.

5. The monitoring programs necessary to enable suitably robust assessments of these factors to be completed will require a significant level of additional funding.

6. A robust reassessment of the success of the package on the status of the stocks needs to be undertaken in three to five years. During this period, the outcomes of the monitoring of dhufish recruitment levels may indicate that an earlier reassessment of the package is required.

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10.0 Appendices

Appendix 1: Review of the West Coast Demersal Scalefish Fishery: Dhufish, Pink Snapper, Baldchin Groper, and Breaksea Cod.

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Executive Summary

Available Information

The survey of the influence of technology on effort clearly demonstrates that while the nominal effort in the WCDS Fishery may remain the same the effective effort has increased significantly. The importance of this is that even if fishers believe things have not declined, given the increase in fishing efficiency even if the performance of the fishery has appeared to have stayed approximately the same over a long period then this really means that the condition of the stock has declined. Effort creep is one of the most important processes that can occur in an input or effort controlled fishery to undermine the efficacy of the management framework. There is no doubt that effort creep has occurred in the WCDS fishery and this means that the actual situation across the fishery will be worse than surface appearance might lead people to believe.

The commercial catch and effort data is made up of monthly summaries of catch and effort which has the effect of biasing catch rates low to variable and unknown amounts. Because of this bias little emphasis should be placed upon the commercial catch rate data, though it could be used for within-year spatial comparisons (which would assume that any biases would be the same in different locations).

In the absence of long time series of good quality fisheries information the assessment strategy adopted (using indicator species, characterizing biological productivity, and estimating fishing mortality) appears to be the best compromise between time and resources available to conduct the required assessments. The use of indicator species is a good strategy in an effort controlled fishery made up of many target species.

The estimates of fishing mortality for dhufish, snapper, and baldchin groper all appear to be based on ageing data that was acceptably representative. This may not have been the case with breaksea cod, but at least that demonstrated that local depletion appears possible.

Dhufish

There are a number of lines of evidence pointing to the dhufish resources being depleted in recent years. The study of effort creep through technological innovation was valuable in identifying that while catch and effort appear to have been relatively stable through time, in fact the effective effort has been increasing, indicating that the stock has been declining.

In addition, the age structure of the population throughout the West Coast has exhibited a significant decline in the proportion of animals older than 13 year, leaving an extended tail of uncommon but old fish. This pattern is typical of a stock that has been severely and rapidly depleted.

When the distribution of effort and catch is plotted on a map the geographical expansion of both effort and catch becomes apparent and this is also a sign that the stock has been exposed to greater levels of fishing mortality. Fortunately for the stock there were four good years of recruitment in the mid-1990s and the fishery has become largely dependent upon these year classes. Subsequent recruitment has not been so marked though it has been variable by zone.

The estimates of fishing mortality indicate that too much effort is being targeted at dhufish in the north and possibly in the south. However, there is some uncertainty in these estimates. Using the model based catch curve analysis, fishing mortality in the Metro zone can appear to be within the target range. However, when the more classical catch curve analysis is used the F estimate in the Metro region, especially from data collected from recreational fishers indicates that fishing mortality is greater than the limit reference point of two times the natural mortality. With the commercial data (a much smaller sample) the fishing mortality appears close to the limit. While there is uncertainty in these analyses it is clear that, at least in the recreational fishing sector, effort is too high in the Metro region and over-exploitation is occurring.

Without significant recruitment soon this can only become worse, which indicates that ongoing monitoring of the stocks is required. The high levels of atresia currently occurring may be compromising successful recruitment because it implies relatively low levels of reproductive activity by mature-age fish. There are clearly risks to the dhufish stocks developing and it would be precautionary to reduce fishing effort. There remains a need to monitor this stock to ensure that recruitment does occur and that the stock does not simply continue to decline.

Pink snapper

Numerous data streams all indicate that the pink snapper stocks are under severe stress. When the distribution of charter boat catches and effort and commercial catch and effort are plotted for pink snapper it is the only species for which the area of the fishery has contracted and the catches and catch rates appear to have declined between 2002/03 and 2005/06. The age structure in the different zones, excluding the distortion of the spawning grounds in Cockburn Sound, indicate severe depletion has occurred to an extent that older fish are now very rare indeed. Worst of all the estimates of fishing mortality are so high that they demand attention and indicate that the snapper stocks are under severe stress from fishing.

The risk if recruitment overfishing is so great that an increase in the legal minimum length is recommended and a reduction in fishing effort targeted at pink snapper be made, it may also be prudent to close Cockburn Sound to snapper fishing. Both commercial and recreational sectors are negatively impacting the stock so it may be necessary to generate novel ways of reducing fishing mortality on snapper.

Baldchin Groper

The fact that baldchin groper change sex and that all males are vulnerable to fishing mortality makes this species potentially more sensitive to fishing pressure relative to a species that does not change sex. In addition, the low discard survivorship and reduced reporting of catches consumed at sea mean that the actual mortality is greater than the records would suggest.

The estimates of fishing mortality are relatively high and indicate either that the spawning season closure has not been operating for long enough to influence the age structure or that fishing effort needs to be restricted still further.

Breaksea Cod

Plots of charter boat catches and catch rates of breaksea cod from 2002/03 and 2005/06 exhibit no apparent changes to the stock status through time. The distribution of catches remains approximately the same as do the catches and catch rates. The fishing mortality estimate indicates that it is possible to locally deplete a population of breaksea cod, which is consistent with the limited movement by this species.

Currently there is insufficient information available to draw any firm conclusions concerning this indicator species. If breaksea cod are to remain an indicator species then it is recommended that a sampling regime be put in place to obtain size and age data, mostly from the recreational and charter catches. Rather than attempt to characterize this species in all zones it may be better to focus attention on this species only in the South zone where it is reported as being a significant component of the targeted catch even though it never makes up a large proportion of the landed catch.

This will limit the amount of work required while maximizing the value to monitoring provided by this species. If such monitoring cannot be put in place then removing this species from the list of indicator species should be considered.

Management Implications

There is a real need to reduce total fishing effort by all sectors, and hence the fishing mortality, in the West coast Demersal Scalefish fishery on dhufish and especially on snapper. The potential for eroding any such changes through effort creep and the expression of latent effort also needs to be accounted for. In addition to adding further restrictions to the commercial sector, it is recommended that strategies be developed, in collaboration with the recreational sector, for finding ways to reduce fishing effort (fishing mortality) imposed by recreational fishers.