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The Western Australian charter boat industry: Working towards long-term sustainability

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USE OF THESIS

The Western Australian charter boat industry: working towards long-term sustainability

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CONFIDENTIALITY

The data presented in Chapter two and three of this thesis have been supplied by the Department of Fisheries, Western Australia. Under the Fisheries Resources Management Act 1994, the identification of individual charter operators is confidential. The confidentiality of all charter operators was protected in this study. As the author of this study, I have signed a confidentiality agreement with the Department of Fisheries.

ABSTRACT

Fisheries agencies and industry are accountable for sustainable fishing practises from all sectors. Throughout Australia, commercial and recreational sectors have been the focus of monitoring programmes and management, yet charter boat industries have been providing a service to fee-paying recreational clients for decades and only recently have the industry become part of those monitoring and management programs. Charter boat industries exhibit characteristics of both commercial and recreational fishing sectors, charter operators are paid for a service and managed under a licensing framework, but their clients adhere to a set of recreational fishing regulations. Unlike the other two sectors, limited catch, effort and socio-economic data exist for the charter boat industry, although more catch and effort data has been collected from the Western Australian charter boat industry since late 2001. The main objective of this study was to assess the spatial and temporal trends in catch, effort and species composition of the Western Australia charter boat industry between 2002/03 and 2007/08 and develop an understanding of the social and economic framework of the industry and its clientele to identify potential implications for management and the future direction of the industry.

The charter boat industry of Western Australia is still developing with a formal licensing framework system since only 2001. The developing nature of the industry may contribute to the substantial latent effort that currently exists, where the average proportion of inactive operators ranged from 41.4% to 54.7% over the study period and license transfers within the charter industry were also highly variable. Overall, the results presented in this thesis show that catch and effort trends have been relatively stable throughout the 6-year study period in all bioregions, with the exception of the Gascoyne. The bioregions have distinct characteristics, each having a diverse array of marine species and clientele characteristics. Extractive and non-extractive activities in the charter boat industry were seasonal, with greater activity levels in the winter (dry season) in the tropical regions and summer in temperate regions. The quantitative assessment of the spatial behaviour of the charter industries overall catch rates and catch rates for pink snapper, dhufish and baldchin groper in the West Coast bioregion, using geostatistical techniques, highlighted the variability in the spatial structure over the study period. Ordinary kriging results showed both high-density and low-density catch rate locations, indicating potential areas of localised

depletion. The social and economic survey showed that the charter boat industry was heavily reliant on word of mouth through their clients, with the vast majority of these clients residing in Western Australia and with a limited number of repeat customers.

This thesis provides the first comprehensive examination of the charter industry in Western Australia and provides important information about the ecological, economic, social and governance perspectives. While this thesis attempted to cover all of these areas, it could not cover all in detail. It is essential that the charter boat industry of Western Australia is continually monitored, as it provides quantitative information that may assist in ensuring the long-term sustainability of the industry and fish stocks.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

- *(i)* *incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;*
- *(ii)* *contain any material previously published or written by another person except where due reference is made in the text; or*
- *(iii)* *contain any defamatory material.*

I also grant permission for the Library at Edith Cowan University to make duplicate copies of my thesis as required.

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CHAPTER 1

THE DEVELOPMENT OF THE CHARTER BOAT INDUSTRY OF WESTERN AUSTRALIA

1.1 BACKGROUND AND INTRODUCTION

Marine fisheries provide a vital contribution to food supplies, employment and culture worldwide (National Research Council, 1998). In recent decades there have been major changes to Australian and overseas fisheries with demands for improved management of resources that incorporate the principles of Ecologically Sustainable Development (ESD) (Department of Environment, Water, Heritage and the Arts, 1992). In Australia, commercial fisheries constitute a multi-billion dollar industry being our fifth largest food producing industry valued at more than $2.2 billion annually (Australian Fisheries Management Authority 2007). Even though fisheries resources are renewable they are not infinite and the need for management is essential for long-term sustainability. In 2000, the United Nation Food and Agriculture Organisation (FAO) estimated that 72% of the world's marine fish resources are fully exploited, overexploited or depleted. This exploitation of fish stocks has come predominantly from an increase in consumer demand, rapid population growth and advances in technology (FAO, 2005).

Fisheries agencies and industry are accountable for sustaining fish stocks and ensuring their future sustainability. In an ideal world, accurate estimates of the abundance of fish stocks would be available to set sustainable harvest levels to accommodate the demands of all fishing sectors. However, in reality, fisheries management is based on imperfect estimates of species numbers, biomass, productivity and incomplete knowledge of population attributes and species distributions (National Research Council, 1998). To address these knowledge gaps, methods for collecting data such as logbook programs, mail, phone and onsite recreational creel surveys have been developed. Data collected through these methods include species composition, catch, fishing effort, biological data, net sizes, areas fished and number of fishers. Data collection methods are typically used to monitor the activities of both the commercial and recreational sectors and together with fishery-independent data, the numbers of fish and fish population characteristics can be estimated (National Research Council, 1998). These estimates are vital for fisheries management, and they form the structure for ensuring the sustainability of a fishery (National Research Council, 1998).

The conceptual framework for fisheries management (Figure 1.1) shows how fisheries data can be used in the management of fish stocks (King, 2007). It highlights the important relationships between fish stocks, management objectives and management regulations and indicates how each component relates to another. This forms the feedback mechanism for managing fisheries sustainability.

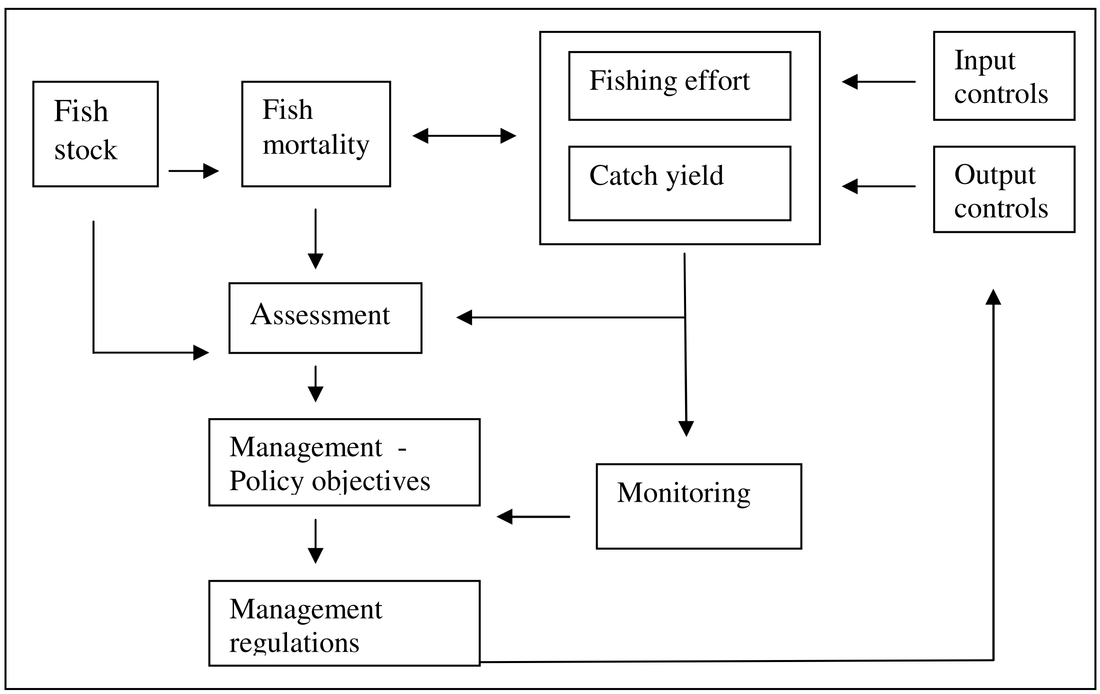

Figure 1.1: Conceptual framework of Fisheries Management (adapted from King, 1995).

Traditionally in Australia, catch and effort data were only collected for the commercial sector, however, information is now collected for the recreational sector (also including charter industries) as agencies began to recognise the need to consider all fishing industries if fish stocks were to be managed effectively (Henry & Lyle, 2003, Wise *et al.*, 2007). In Australia, fishing is considered a national recreational activity and an important element in our way of life (Pepperell, 2001). Recreational fishing surveys have been conducted throughout Australia since the mid 1970s and there have been several hundred recreational fishing surveys to date, however most of these surveys are limited in their scope and scale, for example small temporal or spatial regions (Henry & Lyle, 2003). These surveys cannot necessarily be incorporated into long-term monitoring programs, similar to those of the current management of commercial fisheries (Henry & Lyle, 2003). In 2000/01, the National Recreational and Indigenous Fishing Survey estimated that 3.36 million Australian residents fished at least once during the survey period (Henry & Lyle, 2003) indicating a strong need to consider this sector (including the charter industry) in the management of fisheries.

Charter boat industries throughout Australia have been providing a service to fee-paying recreational clients for decades, however until recently limited data relating to the performance of the industry have been available. In Australia, the States and Territories have adopted different approaches for the management of their respective charter industries (Appendix A). References on catch and effort statistics for specific charter boat industries throughout Australia are limited and to date, no comprehensive study has occurred. This 'knowledge gap' has been noted in the literature. According to Gartside (2000) little attention has been paid to the charter industries of Australia's marine-capture fisheries by both fisheries management and tourism agencies. Studies within Australia are limited and generally describe fundamental summary statistics of the industry and/or regionally-specific information, including: a social assessment of the charter operation in St Helen's Tasmania (Coakes & Gabriel, 2001), the number of charter vessels and the types of activities conducted throughout Australia (Walker, 1997), a summary of the New South Wales charter industry using voluntary information (Steffe *et al.*, 1999), and the future policy for charter fishing operations in Western Australia (Millington, 1990). These studies have provided baseline trends and patterns from the early developing stages of the selected industries, however in recent times there have been no detailed publications about the charter boat industry.

Internationally, statistics on charter boat industries and their associated impacts on fish stocks follow a similar pattern to Australia, studies appear to be limited and focus on small scale regional projects. Studies on the charter industries in United States of America have primarily focused on economics, such as business turnover (Ditton & Vize, 1987) and the costs of charter trips (Dawson *et al*., 1989). There is limited information on charter industries worldwide, particularly with regard to the associated impact on fish stocks. This thesis aims to fill some of this 'knowledge gap' pertaining to information on charter fishing in Western Australia.

The Department of Fisheries (DoF) in Western Australia is responsible for: (1) the conservation of marine and freshwater species in Western Australia; (2) the protection of the environment, including associated food chains; and (3) ensuring that the exploitation of these resources is undertaken in a sustainable manner (DoF, 2006). The management of these responsibilities necessitates the adoption of the principles of ESD, which is a component of Integrated Fisheries Management (IFM), incorporated within the overall Ecosystem-Based Fisheries Management (EBFM) approach (Vieira *et al.*, 2009). ESD aims to ensure that all fishery development is ecologically sustainable in terms of environmental, social, and economic values (Department of Environment, Water, Heritage and the Arts, 1992). Under these principles, the gathering of catch and effort data from commercial and recreational sectors (including charter) together with the collection of data on the social and economic aspects of fishing and fishing industries is required to assist decision makers, and therefore provide a platform for the long-term sustainability of a fishery (Schirmer & Casey, 2005). This approach involves managing the impacts of fishing on target and non-target species, by-catch species and habitats, plus potential indirect impacts of all fishing activities within a region, on the broader ecosystem of that region (DoF, 2005).

The DoF manages three main fishing sectors: commercial, recreational (includes charter) and indigenous, within four marine bioregions: North Coast (Pilbara/Kimberley), Gascoyne, West Coast and South Coast (Figure 1.2). The marine bioregional boundaries are defined by common oceanographic characteristics in the marine environment and climate/rainfall characteristics in the inland river systems (DoF, 2006). Within each bioregion the DoF has selected key 'indicator' species as a way of prioritising which stocks are to be monitored and assessed, as it is not possible to monitor all stocks (DoF, 2011). Indicator species are identified based on their vulnerability, suite, targeted stock for commercial and recreational sectors, economic value and cultural value with is combined with a risk-based approach to also quantify the sustainability risk (Lenanton *et al.* 2006, DoF 2011). The full list of current 'indicator' species is at Appendix B.

The commercial sector was first formally managed by a licensing system in 1899, when the Fisheries Act was introduced and has been managed through a combination of licenses and input and output controls since that time (Lenanton, 1984). Historically, recreational anglers, unlike the commercial sector, were not required to have a license. However, in recent times some licensing arrangements have been implemented for: abalone, marron, south-west freshwater angling, net fishing, rock lobster and a recreational fishing from a boat, as well as adhering to a set of fishing regulations such as bag and size limits (DoF, 2009). The first regional recreational dataset from Western Australia was created in the 1970s and since then many regional surveys have occurred, providing estimates of total harvest for particular areas. Recreational catch and effort data are considerably harder to collect compared to commercial data, as the fishery is 'open' access, so surveys are designed to sample a proportion of the recreational population, where data are statistically aggregated and the total catch, effort and catch rates are estimated (Pollock *et al.*, 1994). The charter industry is part of the recreational sector, but unlike recreational anglers, a licensing framework provides a mechanism for collecting catch and effort data. Since 2001, in Western Australia, there has been a compulsory logbook program in place for the charter industry (Johnson, 2005), collecting catch and fishing effort information that is needed to make effective management decisions (Figure 1.1).

In Australia, the Western Australian charter boat industry has the second largest fleet after Queensland. It is currently managed as a component of the recreational sector, and has provided anglers and tourists with opportunities to explore and utilise the marine environment for decades (Johnson, 2005). The industry was first reviewed in 1990, to ensure the long-term sustainability of fish resources, and to guide the charter industry towards being socially and economically beneficial to communities (Millington, 1990). This review highlighted the need for the industry to move from a previously open-access arrangement to a limited entry industry, therefore operators would require a license to carry out charter activity in Western Australia (Millington, 1990). The consequences of leaving the charter industry as open-access would have been significant in the long-term, with an unregulated or ‘open access’ industry can potentially result in over-fishing, over-capacity and/or conflict between participants (Cartwright 1995).

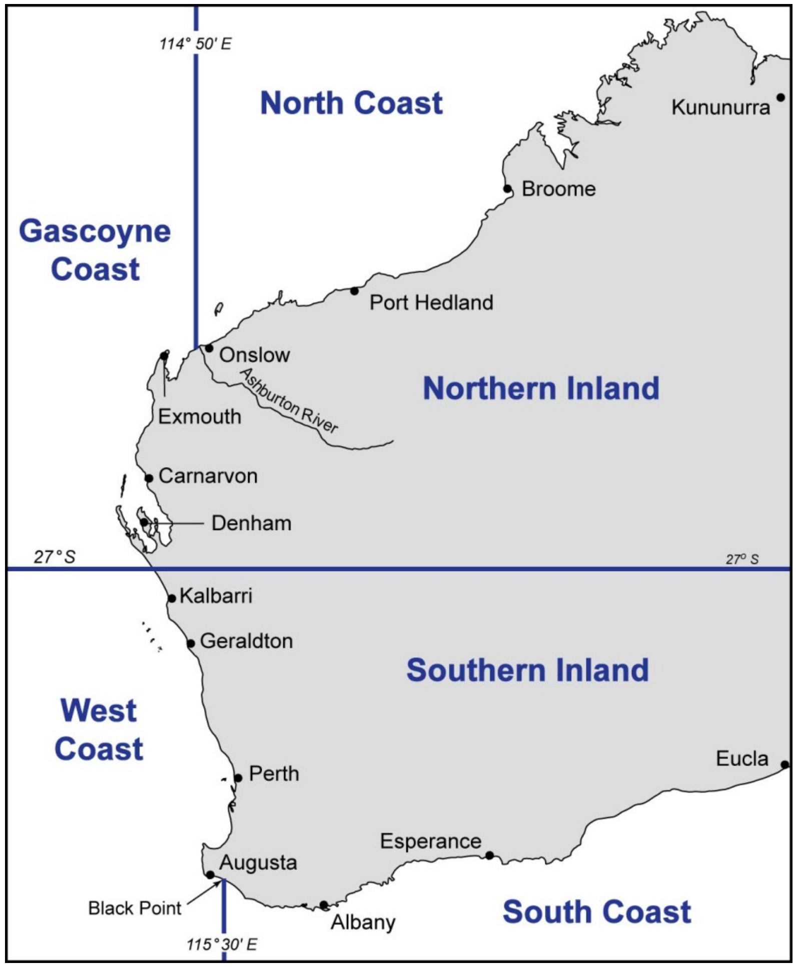

Figure 1.2 Bioregions of Western Australia (DoF, 2006). Note: the north coast is also referred to as the Pilbara/Kimberly bioregion.

Information obtained during the 1990s demonstrates that the charter industry in Western Australia grew rapidly, however since the licensing framework was implemented it has stabilised (Figure 1.3). On the basis of forecast growth in 1998, it was estimated, that if the industry was not formally managed then there may be an exceptionally high number of charter operators working along the coastline by 2010 (Tour Operators Fishing Working Group, 1998). The regulation of the industry has had a stabilising effect and enabled operators to establish reputable businesses and develop a rapport within their communities (Johnson, 2005).

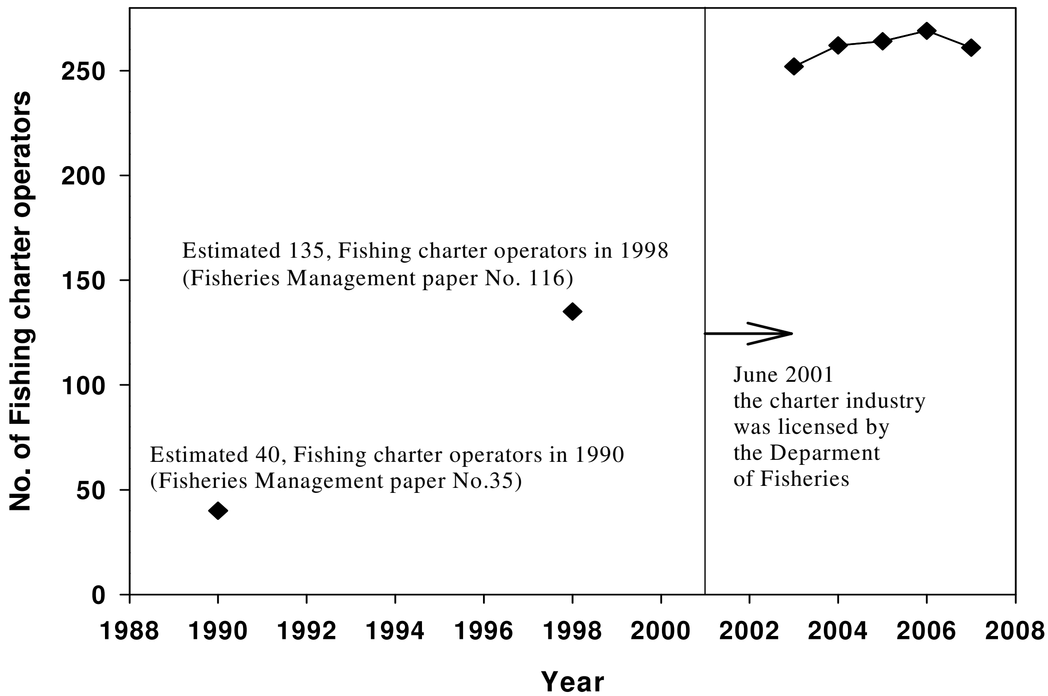

Figure 1.3: The growth of the fishing charter boat industry.

When legislation to regulate the charter industry was passed in June 2001, it was divided into two main license category types: Fishing Tour Operators license and Aquatic Eco-Tourism Operators license. Within each category, there was the provision for a boat-based operation, a combined land/boat (boat size less than 7.5m) based operation and a land-based operation (DoF, 2000). Subsequent legislative changes in 2004 made the Aquatic Eco-Tourism category non-extractive with all forms of fishing strictly prohibited. For those operators who wished to allow clients to fish for a meal whilst on tour, a new license category called Restricted Fishing Tour Operators license was created. These changes resulted in the three licenses which are currently used (Table 1.1). In conjunction with the implementation of the licensing system, a mandatory logbook system began in September 2001 as part of the regulations to facilitate the collection of catch and effort information, and to allow the assessment of the potential effects of charter activities on fish stocks, and the ongoing operations of the industry itself (Johnson, 2005). Logbook programs have been extensively used for gathering data on licensed fisheries and are a relatively inexpensive way to obtain information on catch and effort (Pollock *et al.*, 1994).

Table 1.1: Western Australian Charter Industries License Categories.

License Category	Focus of Activities
Fishing Tour Operators License (FTOL)	Focus is on fishing, with clients able to catch and land fish within recreational fishing regulations.
Restricted Fishing Tour Operator's License (RFTOL)	Focus is on eco-tourism type activities, with clients able to catch fish for a meal during a tour, within recreational fishing regulations. No fish are to be landed or retained beyond the duration of the trip.
Aquatic Eco-Tourism Operator's License (AEOL)	Focus is entirely on eco-tourism activities, where fishing is strictly prohibited.

In 2007, there were 261 Fishing Tour Operators Licenses and 48 of either Restricted Fishing Tour Operators Licenses or Aquatic Eco-Tourism Operators Licenses throughout the State. In 2000/01, as part of the National Recreational and Indigenous Fishing Survey of Australia (NRIFS) the first detailed catch and effort statistics were recorded for the Western Australia charter industry. Results from this survey for Western Australia found that charter industry accounted for 2% of the total scalefish catch (methods defined in Henry & Lyle, 2003) (Figure 1.4). This compared to 72% by the commercial sector, 25% by the recreational sector (excluding charter) and 1% by the indigenous sector (Penn, 2002).

Whilst the majority of the charter boat industry focuses on fishing (extractive), it is important to note that the industry is not solely a fishing industry. It also offers a wide range of touring (non-extractive) opportunities like wildlife observations, sightseeing, diving and snorkeling to clients throughout Western Australia.

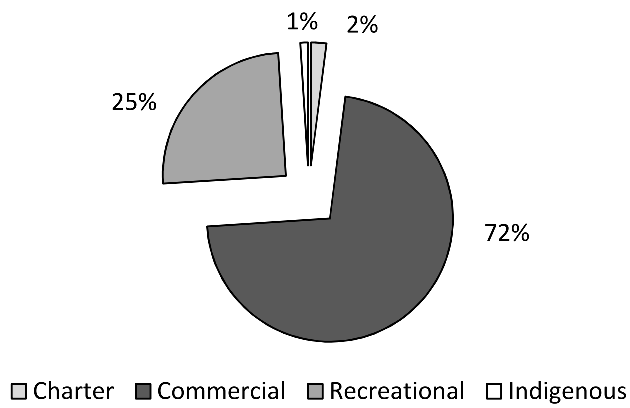

Figure 1.4: Estimated proportional of total scalefish catch taken by each sector (NRIFS, Henry and Lyle 2003).

1.2 AIMS AND OBJECTIVES

The objective of this study was to assess the spatial and temporal trends in catch, effort and species composition of Western Australia charter industry between 2002/03 and 2007/08, and develop an understanding of the social and economic framework of the industry and its clientele to identify potential implications for management and the future direction of the industry.

Aims:

Chapter 2:

Develop a temporal and broad spatial (bioregional) overview on the catch, effort and catch rate of target and non-target species in the charter industry and where appropriate, identify implications for management.

Chapter 3:

Assess the spatial and temporal structures in the charter boat industries catch rates for the West Coast bioregion using geostatistical techniques.

Chapter 4:

Examine social and economic profiles of charter clients in Western Australia to determine why they use charter services and if they were satisfied with the experience, as well as assess the number of license transfers within the industry over time to determine the industries stability together with the financial revenue generated from the licensing framework.

1.3 GLOSSARY OF TERMS

Throughout this thesis the following words will mean:

Charter boat - means a boat that is used to conduct a fishing tour for a commercial purpose in accordance with a fishing tour operator's licence or a restricted fishing tour operator's license (Fisheries Management Resources Act 1994).

Fish - means an aquatic organism of any species (whether alive or dead) and includes — (a) the eggs, spat, spawn, seeds, spores, fry, larva or other source of reproduction or offspring of an aquatic organism; and (b) a part only of an aquatic organism (including the shell or tail), but does not include aquatic mammals, aquatic reptiles, aquatic birds, amphibians or (except in relation to Part 3 and Division 1 of Part 11) pearl oysters; (Fisheries Management Resources Act 1994).

Extractive Tour (Trip) - means a tour for which the central purpose is to provide an opportunity for recreational fishing and may include the provision of fishing guidance, fishing gear, accommodation or transport (Fisheries Management Resources Act 1994).

Non-Extractive Tour (Trip) - means a tour for which the central purpose of which is to provide an opportunity for sightseeing, wildlife observation, accommodation or transport, without any attempt at recreational fishing or provision of fishing guidance or fishing gear.

1.4 SOFTWARE USAGE

Various software packages where used to complete the analysis for this thesis, they include:

ACCESS (Microsoft):	Data storage, analysis
SAS:	Average weight estimations
ARCView (ESRI):	Base mapping of raw catch rate data and study area
ISATIS (Geovariances):	Variography, geostatistical estimation, summary statistics, Ordinary kriging
Excel (Microsoft):	Data preparation and manipulation, graphical representation of data/results and other calculations, spatial correlation Tjøstheim's index A
Word (Microsoft):	Compilation of the thesis.

CHAPTER 2

CATCH AND EFFORT STATISTICS FROM THE CHARTER INDUSTRY OF WESTERN AUSTRALIA

2.1 INTRODUCTION

Fishery management is based on the estimation of either absolute or relative numbers, total mass, and productivity of target fish stocks available for harvest (National Research Council, 1998). To manage those fish stocks in a sustainable manner also requires characterisation of the population structure of the target species (National Research Council, 1998). Both the fisher and fisheries managers require some measure of the order of magnitude of the stock (King, 2007). Most fisheries in the world include large numbers of commercial fishers and/or recreational anglers and it is almost never possible to monitor the catch of every participant (National Research Council, 1998). The assessment of the status of fish stock is often undertaken by the completion and submission of fishing logs through a logbook program. Data from these programs provide a history of relative catch and effort trends for a sector and provide a record of change, should one occur. Traditionally in Australia, most commercial licensed fisheries have a legal requirement to complete fishing logs to participate in the fishery and managers use these as a tool to gather census data about the status of particular fish stocks (National Research Council, 1998).

In contrast to commercial fisheries where traditional logbook methods are used to obtain census catch and effort data about a fishery, recreational catch and effort data are considerably harder to collect as the fishery is often 'open' access. Since surveys of recreational fisheries often require large sample sizes from an unknown population, surveys are designed to sample a proportion of the recreational population, where data are statistically aggregated and the total catch, effort and catch rates are estimated (Pollock *et al.*, 1994). Onsite survey techniques, including creel and roving surveys are usually expensive, which often means that these surveys are not effective tools for ongoing monitoring of recreational catch and effort (National Research Council, 1998). Alternative techniques such as phone diary surveys provide a cheaper option, but for these to be representative of the fishing population, anglers need to be identifiable, such as a registry/license of recreational anglers.

For the charter boat industry, unlike the recreational and commercial sectors, there are some diverse definitions of what characterises a charter industry. In the United States of America under Fishery Conservation and Management charter fishing is defined as "fishing from a vessel carrying a passenger for hire who is engaged in recreational fishing" (16 USC, Chapter 38). In Australia, under the *Fisheries Management Act 1991* "charter boat means a boat that is being used exclusively for recreational fishing in the course of an arrangement under which money or some other consideration is, or is required to be, paid or given by or on behalf of a person or persons for the right to fish from that boat". There is no simple approach for collecting catch, effort, catch rates and socio-economic data for the charter industry as the industry conducts both extractive (fishing) and non-extractive (sightseeing, wildlife observation, accommodation or transport) trips. Because of this, data collection techniques are typically made up of variations used for both the commercial and recreational sectors, which includes traditional logbook systems and survey techniques. Notwithstanding, the industry is still under some form of management, both through commercial techniques such as a licensing system as well as recreational restrictions on catches such as bag and size limits which their fee paying clients must adhere to (Ditton & Vize, 1987). Historical changes to recreational bag and size limits in Western Australia can be found at the DoF website (www.fish.wa.gov.au). In Australia, the charter boat industry is recognised as part of the recreational sector, but the methodology for collecting catch and effort data for them is different, and in most cases a logbook program is more appropriate for the charter industry, thus census data are obtained. Under licensing arrangements, the submission of compulsory fishing logs is easily implemented and administered. The collections of these data are vital to management strategies and assists in the ongoing monitoring of the associated impacts imposed by the charter industry (Steffe *et al.,* 1999).

The primary investigations done by Millington in 1990 on the future policy for charter fishing operations in Western Australia, assisted the DoF in recognising that unregulated growth of the charter industry in Western Australia may ultimately lead to an over-capitalised industry together with over-exploited fish resources (DoF, 2000). The expansion of the industry, combined with a lack of knowledge of its impact on fish resources resulted in a conservative response. In keeping with the objectives of the Fish Resources Management Act 1994 a precautionary approach of ‘capping’ activity was justified until the relative impact of fishing activities on fish resources and fish habitat were established (DoF, 2000).

Without some control mechanisms in place, excessive fishing effort can be a major cause of depleted fish stocks, thus in most cases restricting or decreasing fishing effort reduces the effect on fish stocks and the ecosystem as a whole. In many cases fisheries management involves managing people and their behaviour rather than managing fish, however, without catch and effort data management would not be possible (King, 2007). Thus, a licensing frame for the Western Australian charter industry was implemented.

The charter industry of Western Australia has been operating for decades, however it is only since 2001 that comprehensive catch and effort data have been collected. Limited analyses have been completed on the industries data and this thesis will be the first extensive analysis performed on six years of the data between 2002/03 and 2007/08. The aim of this chapter was to develop a temporal and broad spatial (bioregional) overview on the catch, effort and catch rate of target and non-target species in the charter industry, and where appropriate, identify implications for management.

2.2 DATA PREPARATION

Since September 2001, it has been mandatory for licensed charter operators to provide information about their daily activities through a logbook program which is administrated by the DoF. A daily trip return sheet is submitted for each trip, including instructions on how to fill them out (Appendix C1 to C5). Note there are several versions of the daily trip return sheets as the logbook design has been improved over time. Logbook information is submitted to the DoF by the 15th of every month, where the data are validated and entered into a database. The information collected for each trip in the logbook includes: date of trip, departure and arrival locations, block location of activity (each block is 5 x 5 nm with an identification number), number of clients (total and the number undertaking each activity type), time spent fishing, the number of species kept and released and length measurements of random individuals retained species.

Summary statistics of the logbook data have been produced for extractive activities (fishing, diving (e.g. spear fishing), snorkeling (e.g. using snares) conducted by Fishing Tour Operators, Restricted Fishing Tour Operators and Aquatic Eco-Tourism (Aquatic Eco-Tourism were only included in the 2002/03 and 2003/04 years as the ability to fish using this license category was changed, refer to chapter 1) license holders. The study looks specifically at charter logbook data by financial years and bioregions for the time period 1st July 2002 to the 30th June 2008, six consecutive financial years. An extractive trip refers to any attempt (whether successful or not) to extract, catch and/or hook any aquatic species. Where a charter operator on a single trip has undertaken two types of activities, for example fishing and wildlife observation, then that trip has been included as an extractive trip.

The number of charter licenses for each year and bioregion was extracted using the DoF licensing database called FLAMS (Fisheries Licensing and Monitoring System). In this study, the data extracted from FLAMS formed the baseline for the total number of charter licenses each year and for each bioregion.

The total number of clients by year and bioregion was calculated from the number of clients recorded on each return. The total number of clients fishing (*F*), was calculated from extractive trips e.g. the number of clients fishing, the number of clients diving (extractive trips only) and the number of clients snorkeling (extractive trips only). Catch was calculated separately as the total number of retained fish (*C*) and released species. Catch rates (*CR*) were calculated by dividing the total number of retained catch (*C*) by the total effort (*F*) (therefore the number of clients fishing), to obtain the number of fish per client per annum.

$$CR = {}^{C}/_{F}$$

The total catch, total number of clients, total number of clients fishing (effort) and catch rate data were calculated by month. Multiplicative classical decomposition of time series was then applied to assess the trend and variability of the data over the study period.

As the data were calculated on a monthly basis and as their plots indicated the presence of a yearly periodic pattern, a 12 point centered moving average was applied to derive seasonal indices for the data.

The 12 point centered moving average is given as

$$M_{12}(t) = \frac{\sum_{j=-5}^{6} Y(t-j) + \sum_{j=-6}^{5} Y(t-j)}{24}$$

Here $Y(t)$ and $M_{12}(t)$ denote the datum and the 12 month centered moving average for month *t*.

The seasonal index $S(t)$ may be computed as

$$S(t) = \frac{Y(t)}{M_{12}(t)}$$

Next the irregular component is removed from $S(t)$ by computing the average seasonal component $s(t)$ for each of the 12 seasons.

The data are then deseasonalised by division by the corresponding seasonal indices:

$$\hat{Y}(t) = \frac{Y(t)}{s(t)}$$

Now regression analysis can be performed on the deseasonalised data to obtain an appropriate trend model. In this case the following trend models were investigated:

Linear trend

$$\hat{Y}(t) = b_0 + b_1 t$$

Quadratic trend

$$\hat{Y}(t) = b_0 + b_1 t + b_2 t^2$$

Cubic trend

$$\hat{Y}(t) = b_0 + b_1 t + b_2 t^2 + b_3 t^3$$

Quartic trend

$$\hat{Y}(t) = b_0 + b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4$$

Seasonal estimate smoothing constant for seasonality estimate length of seasonality new smoothed value (Hanke & Wichern, 2005).

Since the logbook data only provided length data of the catches, calculating the total biomass of the retained catch was estimated using length to weight relationship (LWR) for each species (Appendix D). From these relationships an average weight data was determined for each species per year and bioregion. This average weight was then multiplied by the total number of fish retained for each species, to produce an estimated total retained biomass per species. Note: not all retained species have sufficient lengths and/or LWR available for calculation. To estimate the overall total retained biomass for each year, and to include those species that do not have sufficient data available, the total weight of those species that can be calculated are multiplied by the number of all retained species, divided by the total number of those species with an estimated weight, refer to the following equation (DoF, 2010).

$$\text{Total 'missing' weight} = \frac{\text{Total number of fish without a LWR} \times \text{Total weight of fish with a LWR}}{\text{Number of fish with a LWR}}$$

This provided only an approximate total retained biomass of all species retained and should be used as an indicator only of the total retained biomass. Biomass cannot be estimated for released species, as lengths of released fish were not recorded. Note the data reported by the charter industry have not been independently validated for accuracy. The total number of fish retained and released reported in this thesis may differ to other reports, as the DoF corrects data and/or outstanding late returns are received.

2.3 RESULTS

The number of licenses issued by the DoF for each financial year and by bioregion, varied only marginally throughout the study period (Table 2.1). Variation occurs when new licenses were created and/or licenses are cancelled or not renewed at the end of each financial year. The proportion of license types issued was dominated by the Fishing Tour Operators boat based licenses (FTOL). Note, there were no Aquatic Eco-Tourism Operator's Land based category licenses (AEOL) issued since the category was first created. The West Coast bioregion had the highest number of licensed operators, followed by the Pilbara/Kimberley, Gascoyne and South Coast bioregions between 2002/03 and 2007/08.

Table 2.1: The number of licenses issued by the DoF each year and bioregion.

Year	**FTOL (Boat based)**	**FTOL (Land based)**	**FTOL (Boat & Land based)**	**RFTOL (Boat Based)**	**RFTOL (Land Based)**	**RFTOL (Boat & Land based)**	**AEOL (Boat Based)**	**AEOL (Boat & Land Based)**
				South Coast				
2002/03	18	2	1	0	0	0	3	0
2003/04	17	4	1	0	0	0	5	0
2004/05	18	4	1	3	0	0	1	0
2005/06	18	4	2	3	1	0	1	0
2006/07	18	4	2	2	1	0	1	0
2007/08	18	4	2	5	1	0	1	0
				West Coast				
2002/03	123	4	4	0	0	0	16	2
2003/04	126	4	4	0	0	0	17	3
2004/05	130	4	4	16	0	2	0	1
2005/06	131	4	4	16	2	2	2	1
2006/07	132	3	3	15	1	2	2	2
2007/08	131	3	3	17	1	2	2	2
				Gascoyne				
2002/03	68	2	1	0	0	0	12	1
2003/04	73	4	2	0	0	0	14	0
2004/05	73	4	3	13	0	0	1	0
2005/06	75	3	3	14	1	0	2	0
2006/07	75	4	3	13	0	0	2	0
2007/08	75	4	4	15	0	0	1	0
				Pilbara/Kimberley				
2002/03	77	5	14	0	0	0	14	0
2003/04	83	6	13	0	0	0	15	0
2004/05	85	6	12	12	0	1	1	0
2005/06	87	6	13	16	0	1	2	0
2006/07	88	7	15	15	0	0	2	0
2007/08	88	7	15	17	0	0	2	0

In total, 843,812 clients participated in charter activities in Western Australia between 2002/03 and 2007/08. The number of clients recorded per financial year increased from 133,188 in 2002/03 to 151,921 in 2007/08, with an overall average of 140,000 clients per financial year. In comparison, the total number of trips, including both fishing and non-extractive trips, showed a slight decline over the study period (Figure 2.1). The majority of trips undertaken by the charter boat industry were fishing trips, which was consistently higher than non-extractive trips (Figure 2.1).

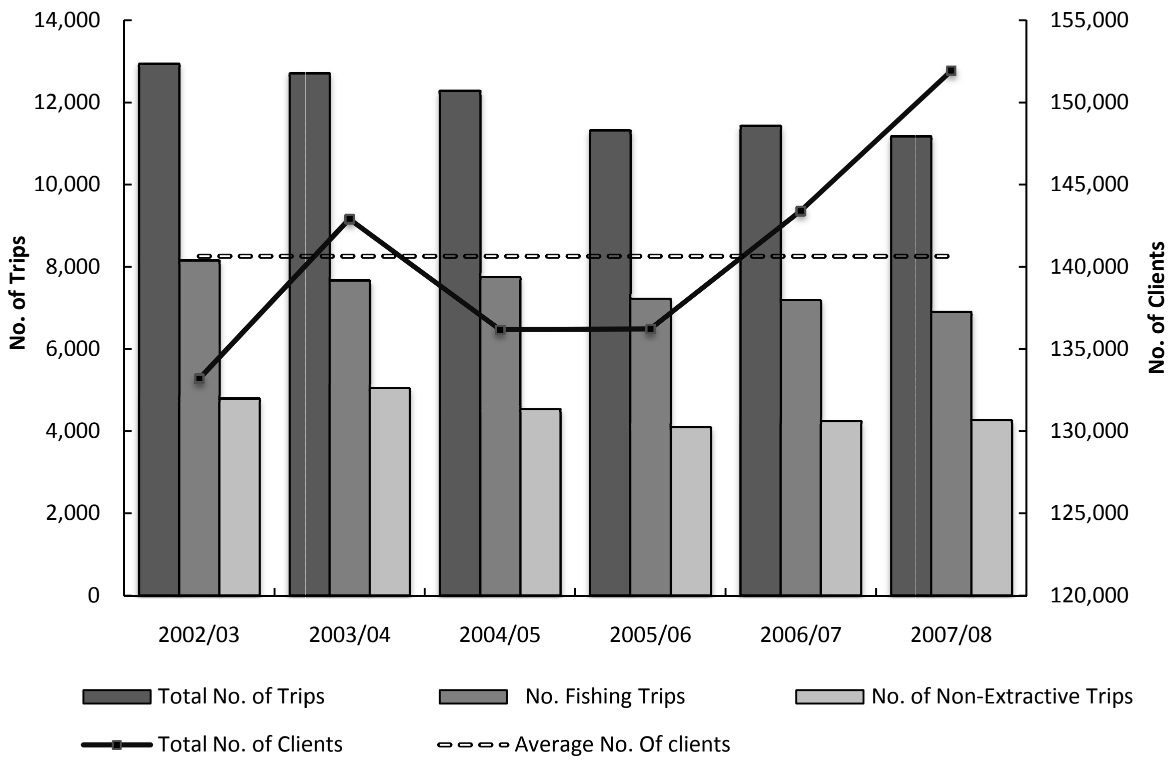

Figure 2.1: The total number of clients and trips, fishing trips and non-extractive trips undertaken by the charter industry of Western Australia between 2002/03 and 2007/08.

The total numbers of clients over the study period at a bioregional level showed a general increase in the West Coast and Pilbara/Kimberley bioregion, whilst client numbers were highly variable in the South Coast and client numbers had a declining pattern in the Gascoyne bioregion (Figure 2.2). The West Coast bioregion had the highest number of clients over the study period with an average of 62,676 clients participating in charter activity per financial year, whilst the South Coast bioregion had the lowest number of clients, averaging only 5,511 clients per financial year (Figure 2.2).

The total numbers of trips in each bioregion over the study period were variable, with a notable decline in recent years. The West Coast bioregion accounts for the highest total number of trips, 26,392 throughout the study period, compared with 24,329 trips in the Pilbara/Kimberley, 16,392 trips in the Gascoyne, and the South Coast had the lowest total number of trips with 3,557. The Pilbara/Kimberley bioregion had the highest number of extractive trips (fishing) which accounted for 81% of all trips in the bioregion (Figure 2.2). In comparison, the Gascoyne bioregion had the highest number of non-extractive trips which accounted for 60% of all trips in the bioregion. In the West Coast bioregion, the number of extractive trips was greater than non-extractive trips, with 61% of all trips in the bioregion extractive. In the South Coast bioregion, 62% of all trips over the study period comprised extractive activity. Overall, extractive trips were predominant, with the Gascoyne bioregion as the only notable exception.

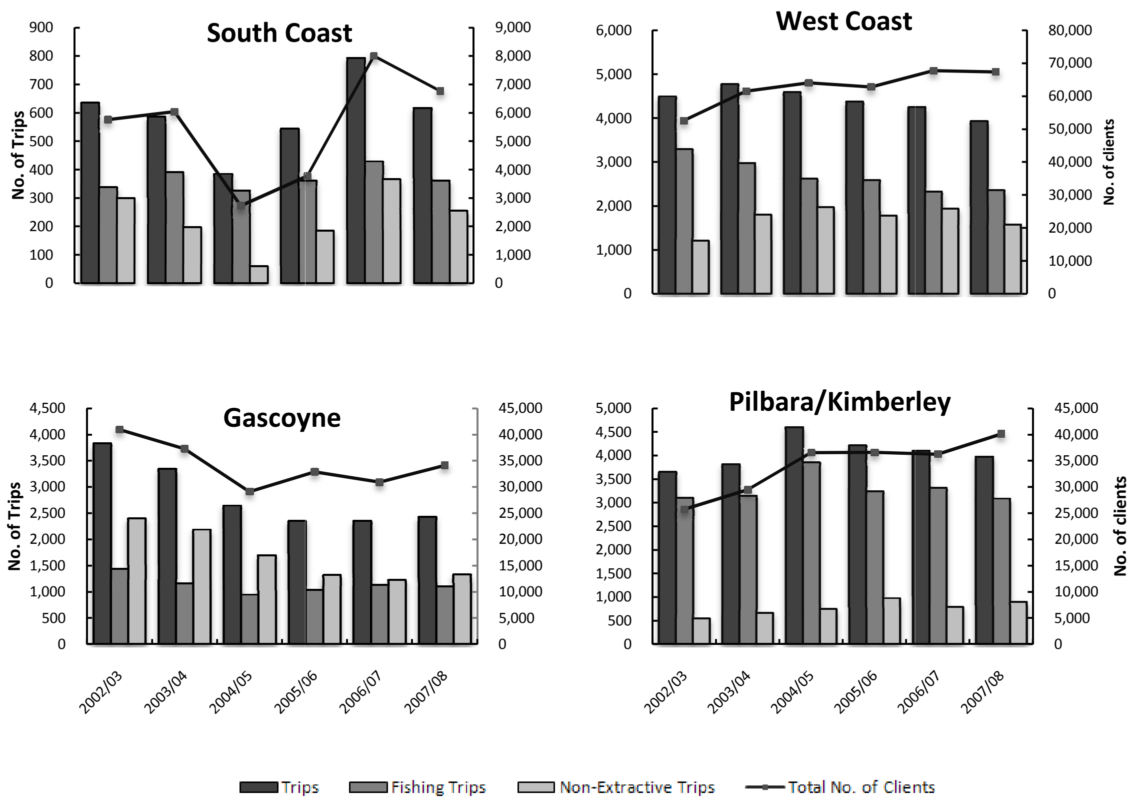

Figure 2.2: The total number of clients and trips, fishing trips and non-extractive trips in the South Coast, West Coast, Gascoyne and Pilbara/Kimberley bioregion.

In the West Coast and Gascoyne bioregions the number of active fishing operators generally decreased over the study period, however in the South Coast and

Pilbara/Kimberley there was no obvious patterns (Table 2.2). In 2002/03, as many as 94 charter operators actively fished in the West Coast bioregion, however, by 2007/08 that had decreased to just 76 operators. In the Gascoyne bioregion there was a decrease from 46 active fishing operators in 2002/03 to 36 in 2007/08. In comparison, the Pilbara/Kimberley increased from 63 active fishing operators in 2002/03 to 73 in 2004/05, which then declined to 59 active fishing operators in 2007/08. In the South Coast bioregion the number of active fishing operators varied between 10 and 14 during the study period.

In contrast to the number of active charter fishing operators, the number of inactive operators, with the capacity to fish, generally increased across all bioregions (Table 2.2). The greatest relative difference in the number of active fishing operators occurred in the Gascoyne bioregion, which had a 60% decrease between 2002/03 to 2007/08. Other bioregions followed a similar pattern, with a decrease of 54%, 51% and 44% in the West Coast, Pilbara/Kimberley and South Coast, respectively. The number of inactive fishing operators incorporates the number of fishing licenses (FTOL and RFTOL only, Table 2.1) issued, compared to the number of active fishing operators per bioregion.

Table 2.2: Number of charter operators actively fishing per year, per bioregion and the number of charter operators who are licensed to fish, but are inactive.

	Number of Active Fishing operators				**Number of Inactive Fishing operators**			
Year	Pilbara/ Kimberley	Gascoyne	West Coast	South Coast	Pilbara/ Kimberley	Gascoyne	West Coast	South Coast
2002/03	63	46	94	12	33	25	37	9
2003/04	70	42	92	12	32	37	42	10
2004/05	73	36	87	10	43	57	69	16
2005/06	66	35	85	13	57	61	74	15
2006/07	68	40	75	13	57	55	81	14
2007/08	59	36	76	14	68	62	81	16

Of the total number of active fishing operators, 31% conducted between one and ten fishing trips per financial year (Figure 2.3) of which 11% of those operators reported only one or two fishing trips per financial year. The number of charter operators that conducted between 11 and 20 fishing trip per financial year, was 14% and the percent declined further as the number of fishing trips increased. The highest number of fishing trips undertaken in any one year was 280 in 2004/05. Only 1% of charter operators conduct more than 200 trips per financial year.

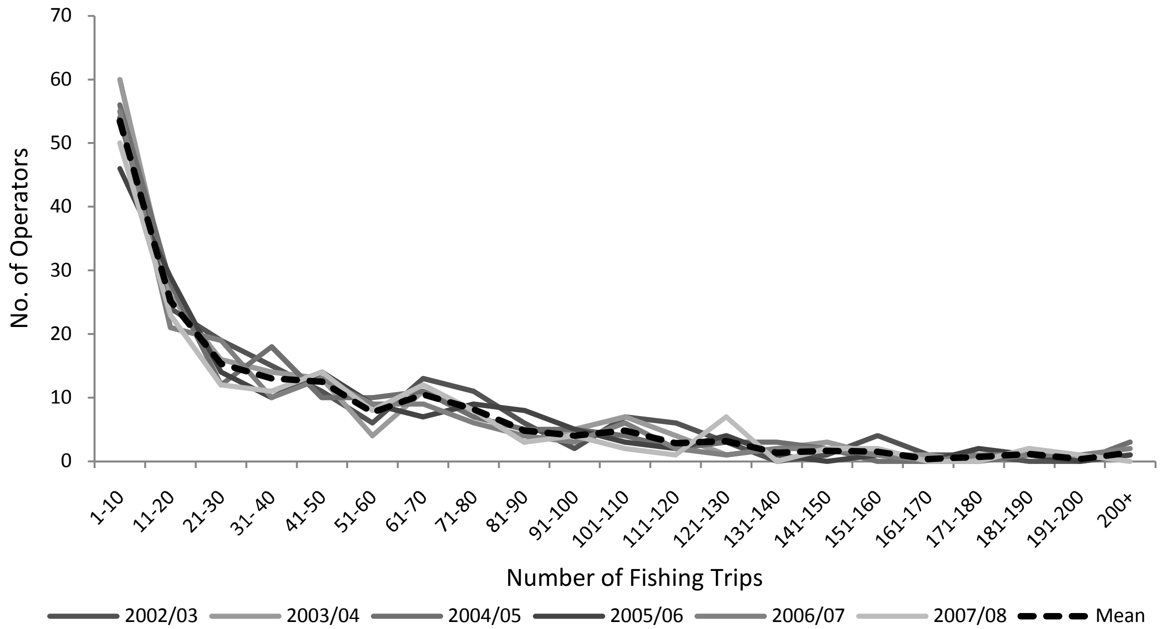

Figure 2.3: The number of active fishing charter operators by the number of fishing trips conducted each year, including the mean over the study period.

In the South Coast bioregion, the top ten fishing operators accounted almost the entire catch (Figure 2.4) however, the number of active fishing operators in the bioregion was only 12.3 per year (Table 2.2). In the West Coast bioregion, an average 58% of the total retained catch was accounted by the top ten fishing operators and in the Pilbara/Kimberley bioregion this figure was 61%. In comparison, 86% of the catch was accounted by the top ten operators in the Gascoyne bioregion, where seven of those operators remained the same in each financial year over the entire study period. In the Pilbara/Kimberley four of the top ten operators were the same in each year, however in the South Coast and West Coast only three and two remained the same for the entire study period.

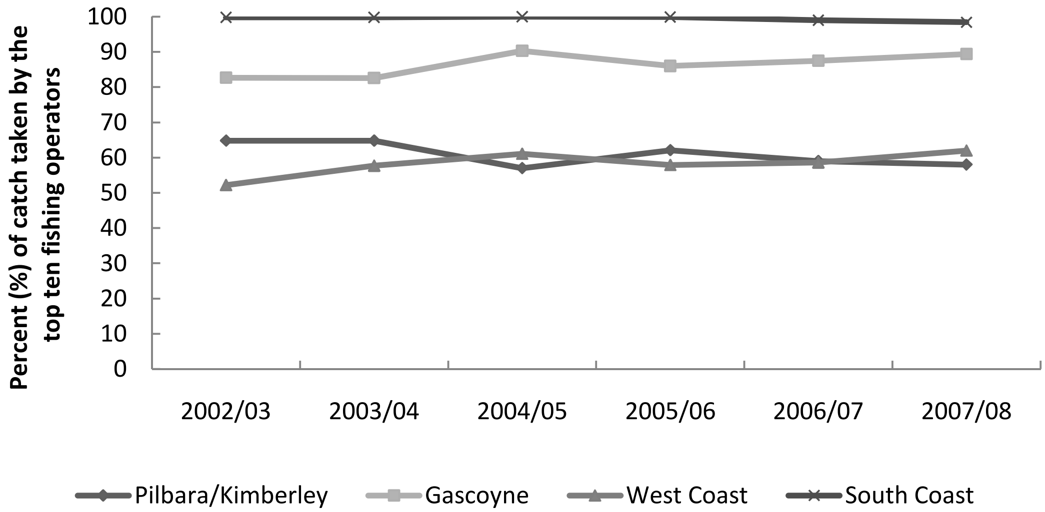

Figure 2.4: Percent of total retained catch by the top ten fishing charter operators per bioregion for each financial year.

Catch and effort data varied seasonally in all bioregions, with high catch and effort in the summer months in the South and West Coast bioregions and high catch and effort in the winter months (dry season) in the Gascoyne and Pilbara/Kimberley bioregions (Figure 2.5 and 2.7). Catch rates also tended to be seasonal in the Pilbara/Kimberley and West Coast bioregions, however the seasonal variability in catch rates in the Gascoyne decreased over the study period, and in the South Coast, catch rates did not follow a seasonal pattern (Figure 2.5).

The number of clients fishing (effort) and the overall total number of clients shared inter annual trends in most bioregions, with the exception of the Pilbara/Kimberley. In the Gascoyne and West Coast bioregions, the number of clients fishing decreased over the study period, whilst in the South Coast bioregion the number of clients fishing followed a quadratic trend (figure 2.8 - 2.11) and the Pilbara/Kimberley bioregion remained fairly consistent throughout the study period (Figure 2.6). The percentage of the total number of charter clients who fished, decreased over time in the Gascoyne, and remained stable at about 40% in the Pilbara/Kimberley. In the South Coast the percentage was highly variable and for the West Coast there was quasi periodic pattern with a declining trend.

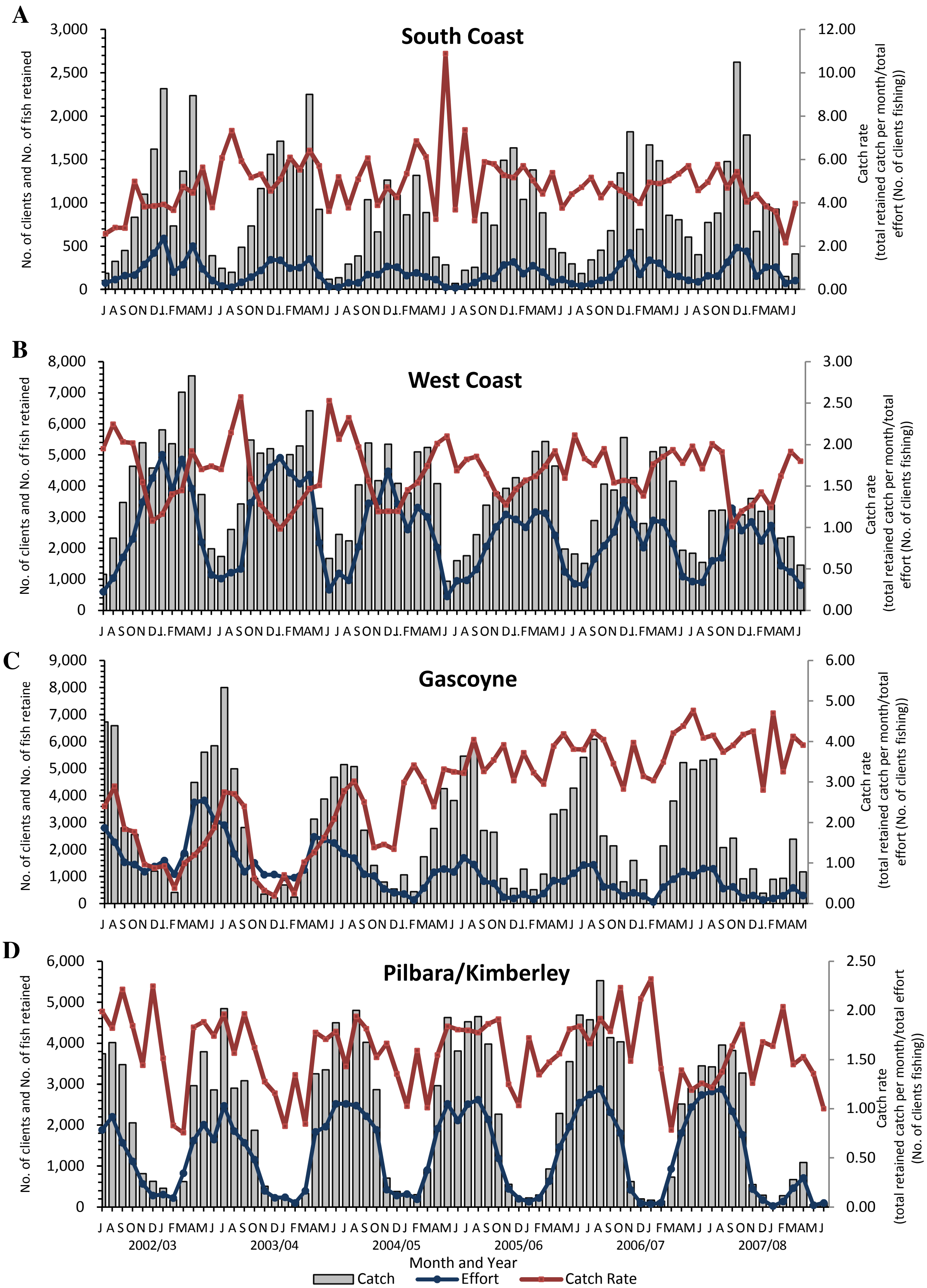

Figure 2.5: Monthly catch, effort and catch rates (total retained catch/total effort (number of clients fishing) by month) by month from July 2002 – June 2008 for the South Coast (A), West Coast (B), Gascoyne (C), and Pilbara/Kimberley (D) bioregion.

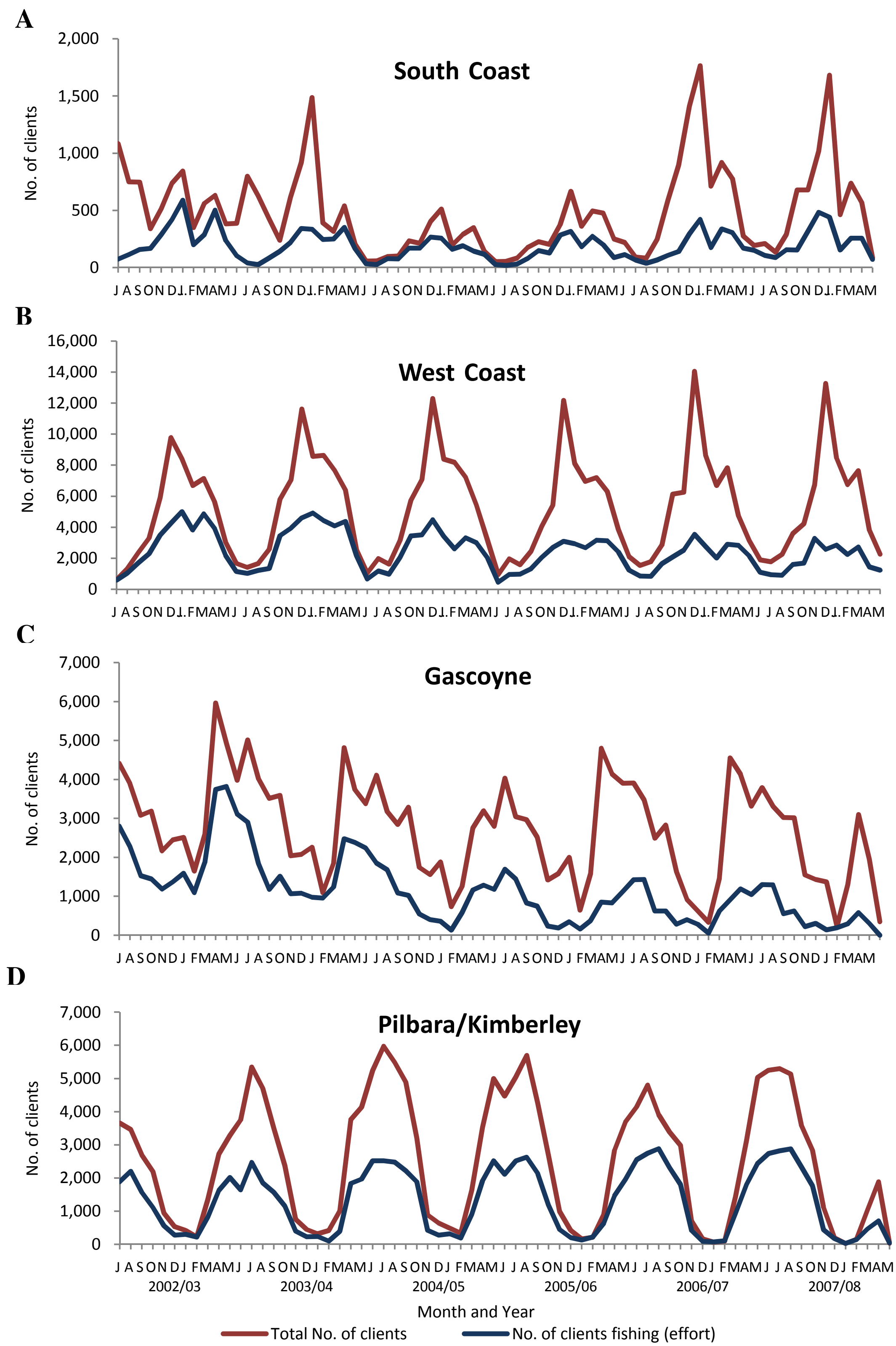

Figure 2.6: The number of clients fishing and the overall total number of clients by month from July 2002 – June 2008 for the South Coast (A), West Coast (B), Gascoyne (C), and Pilbara/Kimberley (D) bioregions.

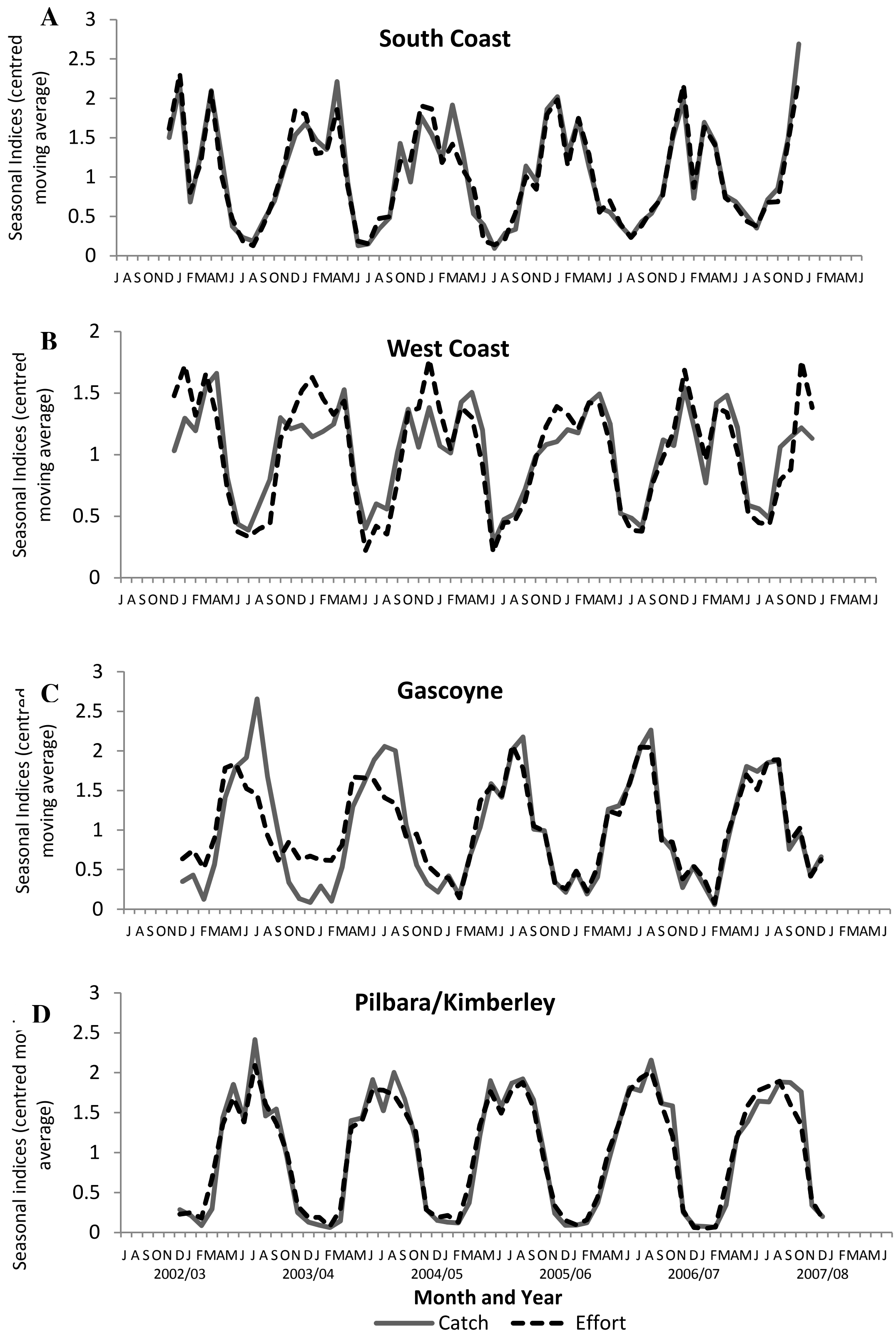

Figure 2.7: The seasonal index for catch and effort by the centred moving average from July 2002 – June 2008 for the South Coast (A) West Coast (B), Gascoyne (C) and Pilbara/Kimberley (D) bioregions.

Catch, effort and catch rates were strongly influenced by seasonality, were periodic and varied between the bioregions (Figure 2.7). In the South Coast, West Coast and the Pilbara/Kimberley bioregions, the number of clients over the study period had quadratic trends, whilst the Gascoyne bioregion had a declining linear trend (Figures 2.8 -2.11). For the number of client fishing (effort), the West Coast bioregion had a linear trend, while all other bioregions had quadratic trends over the study period. In contrast the catch rate trends in the South and West Coast displayed a quadratic and quartic trend, respectively, whilst the Gascoyne and Pilbara/Kimberley bioregions showed linear trends.

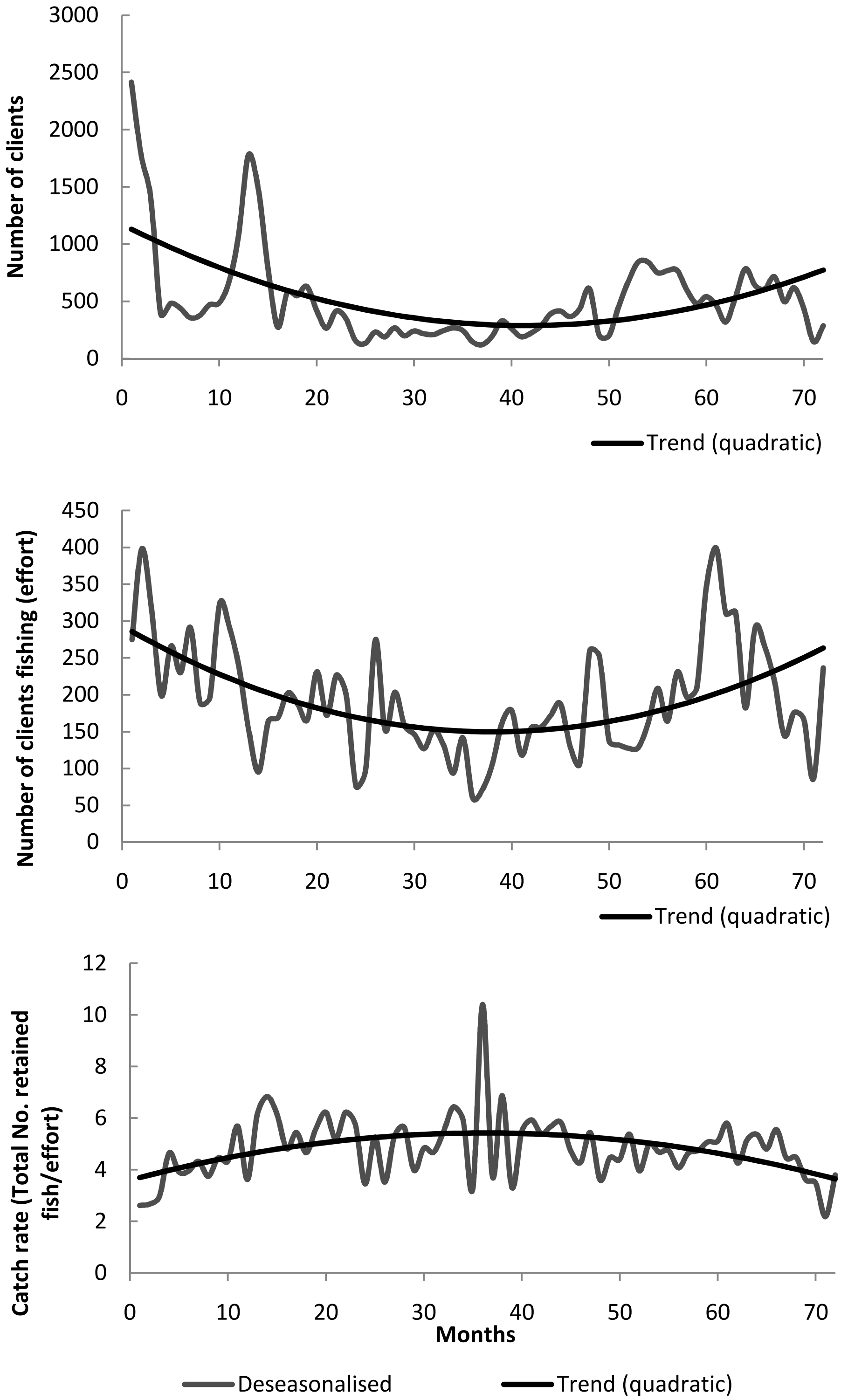

Figure 2.8: Trends fitted to the deseasonalised total number of clients, number of clients fishing and catch rate (retained species/effort) for the South Coast bioregion.

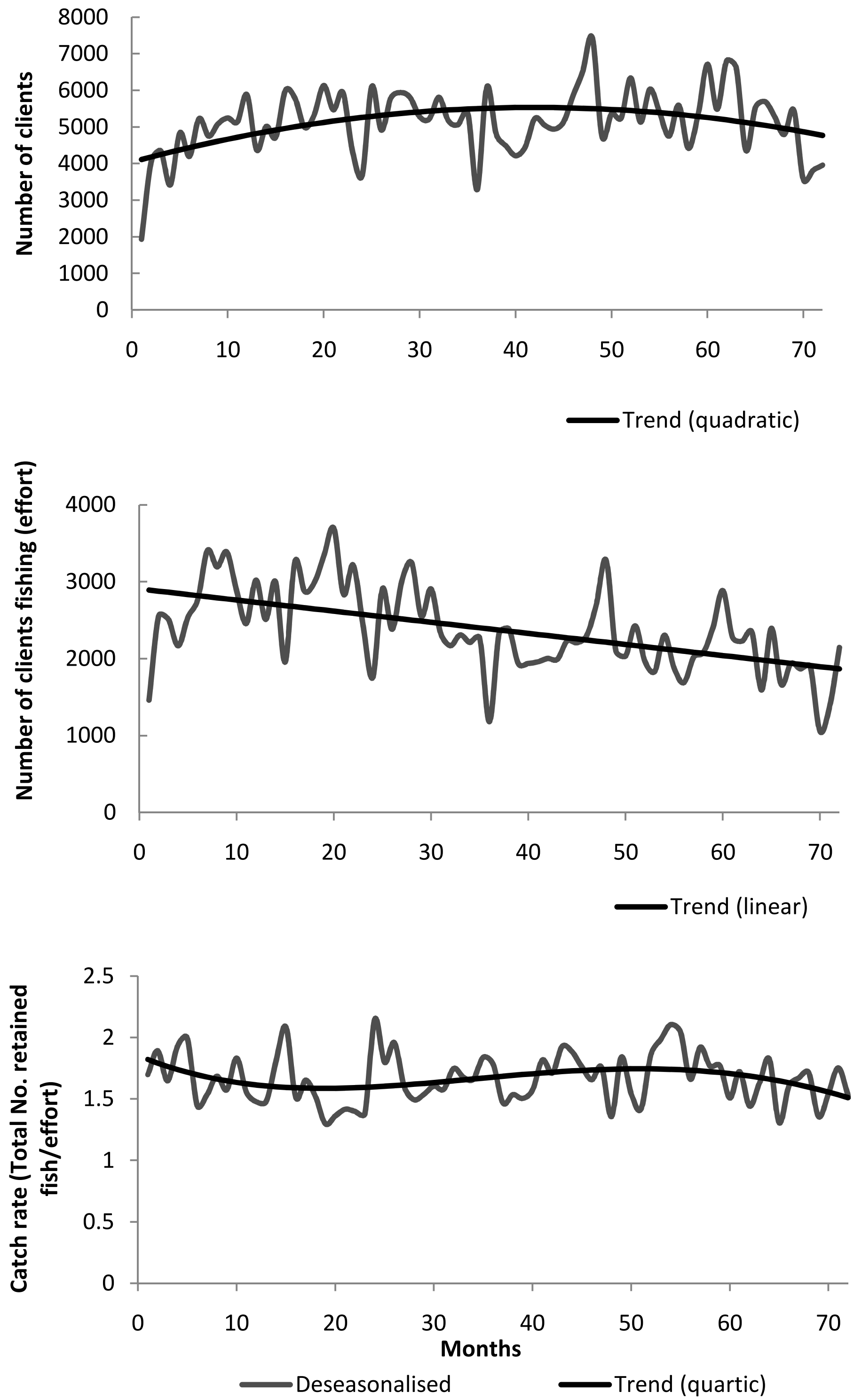

Figure 2.9: Trends fitted to the deseasonalised total number of clients, number of clients fishing and catch rate (retained species/effort) for the West Coast bioregion.

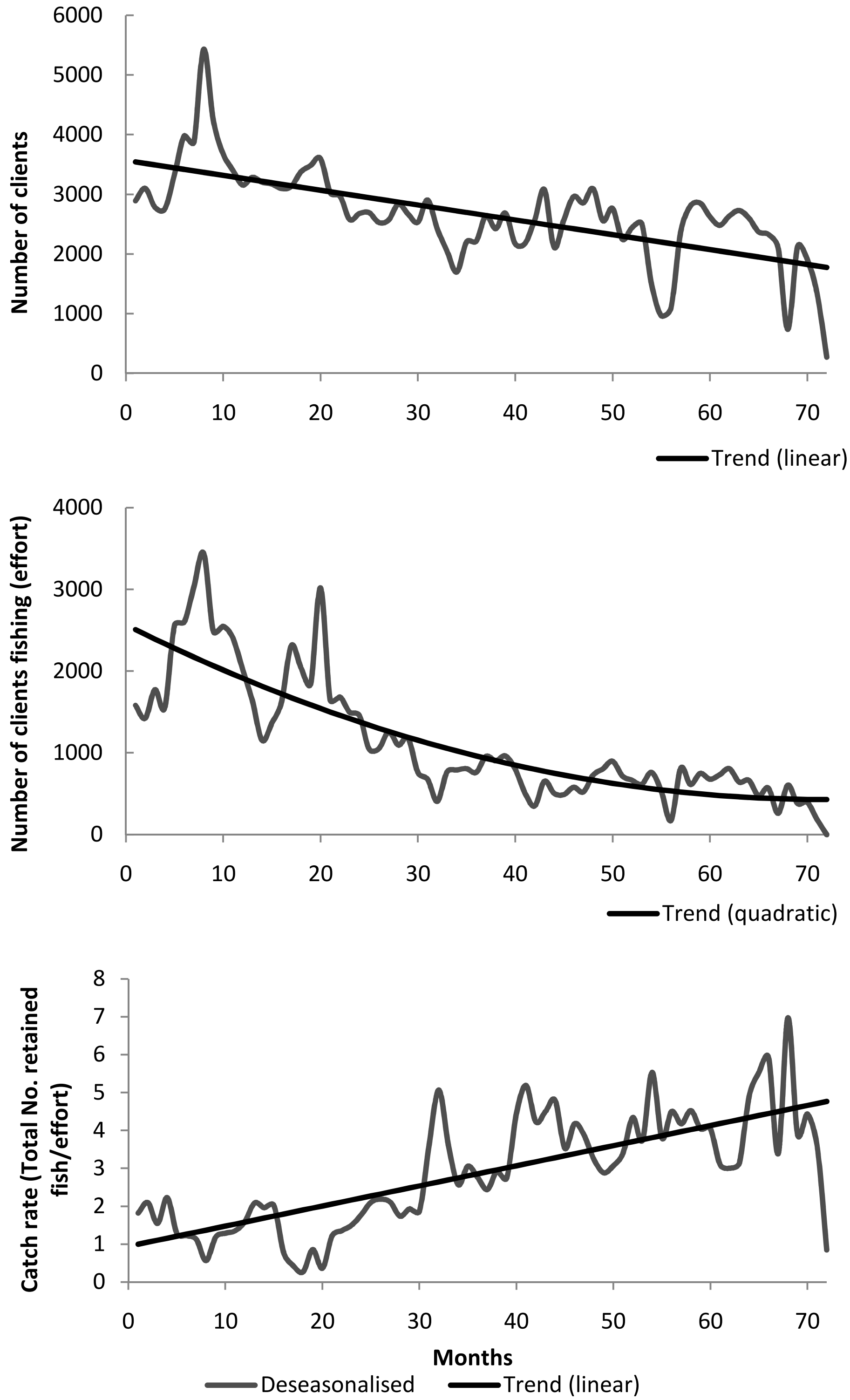

Figure 2.10: Trends fitted to the deseasonalised total number of clients, number of clients fishing and catch rate (retained species/effort) for the Gascoyne bioregion.

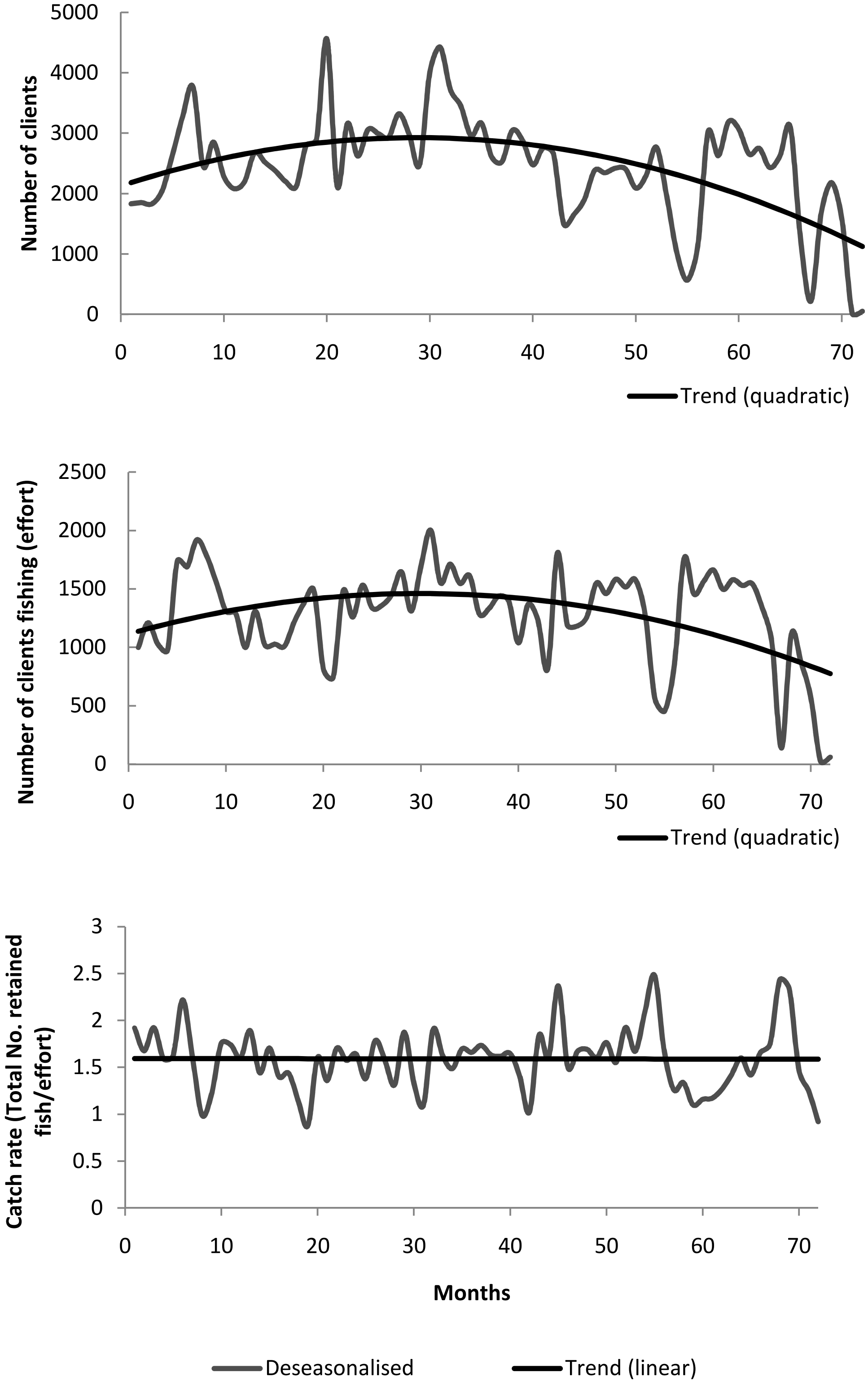

Figure 2.11: Trends fitted to the deseasonalised total number of clients, number of clients fishing and catch rate (retained species/effort) for the Pilbara/Kimberley bioregion.

A total of 779,958 fish were retained by the charter industry between 2002/03 and 2007/08. The highest number and estimated total biomass of fish was retained in 2002/03, with 143,315 fish or 312 tonnes retained (Tables 2.3 and 2.4). The lowest total number and estimated total mass of retained fish was in 2007/08, when 117,309 fish or 276 tonnes were retained. On average over the study period, 129,993 fish or 290 tonnes were retained per financial year. The total number of fish released ranged between 77,021 in 2007/08 to 94,672 in 2004/05 (Table 2.3). The average number of released fish was 88,792 fish, which accounts for 32% of the average catch per financial year.

Table 2.3: Total number of all species retained and released and the estimated total mass (tonnes) retained per year by the charter industry (Note: Total biomass is only approximate, refer to data preparation).

Year	Total No. Retained fish	Estimated Total Biomass (tonnes)	Total No. Released fish	Total No. of fish
2002/03	143,315	312	94,361	**237,676**
2003/04	133,308	281	89,997	**223,305**
2004/05	127,944	283	94,672	**222,616**
2005/06	126,679	286	88,296	**214,975**
2006/07	131,403	301	88,405	**219,808**
2007/08	117,309	276	77,021	**194,330**

The majority of species, with the exception of one, amongst the top 20 retained and released species for all years and bioregions combined (Table 2.4) were demersal species, therefore species that typically live on or near the bottom (DoF, 2007b). Pink snapper accounted for the highest number of fish retained and released and represented 17.8% and 9.9% of the total number of fish retained and released, respectively throughout the study period. Whilst this species dominated the catch over the study period, the total number of pink snapper retained and released remained relatively stable. Western rock lobster was the only invertebrate species in the top 20, with all other species scalefish.

Table 2.4: The top 20 total number of retained and released species for all years and bioregions combined (Refer to Appendix E for scientific names of species).

Species composition	**Species Name**	**Total No. Retained**	**Total No. Released**
Demersal	Pink snapper *	138,821	52,694
Demersal	Sweetlip emperor	59,718	26,703
Demersal	Bight redfish *	42,187	3,771
Demersal	Spangled emperor *	40,668	5,892
Pelagic	Skipjack trevally	30,848	4,588
Demersal	Red emperor *	27,693	7,493
Demersal	Breaksea cod	24,465	3,784
Demersal	Blue-lined emperor	23,728	19,597
Demersal	Swallowtail	22,738	2,563
Demersal	Emperors, unidentified	20,352	33,840
Demersal	Western Australian dhufish *	19,904	8,865
Demersal	Baldchin groper *	19,181	6,892
Demersal	White-blotched rankin rockcod *	18,410	2,462
Demersal	Queen snapper *	16,361	376
Demersal	Fingermark bream	15,321	23,444
Demersal	Mangrove jack	11,705	18,169
Demersal	Sea sweep	11,399	1,553
Demersal	Coral trout	9,963	5,713
Demersal	Saddle-tailed seaperch	9,950	3,978
Demersal	Western rock lobster	9,595	3,622
	Total	**779,958**	**532,752**

* - Denotes indicator species – refer to Appendix B

Within the South Coast bioregion, the species that comprised the majority of the catch were bight redfish and swallowtail, which accounted for 53% of the catch across all years (Table 2.5). An increase in the Australian herring numbers retained occurred across years, whilst pink snapper and queen snapper showed some variability in the number retained over the study period. The top five species retained accounted for 72.6% of the total retained catch. Bight redfish recorded the highest number of released fish (Table 2.5) and accounted for 31% of all released species in the bioregion over the study period. Australian herring was the next most returned species, accounting for 15.6% of released fish.

The West Coast bioregion catch was dominated by pink snapper (Table 2.6), which accounted for 24% of the total retained catch throughout the study period. The catch of pink snapper remained consistent over time as did baldchin groper. Other key species with high catches included skipjack trevally, sweetlip emperor, breaksea cod, dhufish, baldchin groper, western rock lobster and queen snapper. Several species exhibited declining catches, including samson fish, sergeant baker, coral trout, Australian herring and king george whiting. The top five species retained accounted for 54.3% of the total retained catch. The total number of species released was variable over the six-year study period. Pink snapper was the most commonly released fish in all but one year. Samson fish, sweetlip emperor dhufish and baldchin groper were also discarded in high numbers. The total number of baldchin groper released, fluctuated between 683 and 969 in 2002/03 to 2006/07 and then it more than doubled to over 2000 in 2007/08. The total number of released samson fish was stable in the first three years of the study period, peaked at 5,047 in 2004/05, but then declined to 1,811 in 2007/08.

The number of retained and released fish in the Gascoyne bioregion were mostly comprised of pink snapper (Table 2.7) which accounted for 30% of the total catch throughout the study period. Other key species with high catches included the emperor species; sweetlip, spangled, blue-spotted, blue-lined and red emperor. Catches of the majority of the species were relatively consistent throughout the study period. The number of retained goldband snapper increased from 71 in 2002/03 to 2,062 in 2007/08. Similarly, the catches of rosy jobfish increased from 37 in 2002/03 to 1,358 in 2007/08. The numbers of unidentified emperors were variable throughout the study period, and then in 2007/08 there was a marked increase from 942 to 2,156. The number of blue-spotted emperor retained decreased from 1,187 in 2002/03 to only 26 in 2007/08. The top five species retained accounted for 68.2% of the total retained catch. The total number of released species declined between 2002/03 and 2007/08. The number of spangled emperor released decreased from 1,472 in 2002/03 to 398 in 2007/08 and the number of pink snapper released decreased from 5,145 to 2,865 in 2007/08 over the same period. Chinaman cod, sweetlip emperor and blue-lined emperor were also discarded in high numbers throughout the study period.

The Pilbara/Kimberley catch was not dominated by a single species but rather comprised a number of key species, including spangled emperor, saddle-tailed seaperch, mangrove jack, blue-lined emperor, red emperor and barramundi. Catches of these six species catches were similar and consistent throughout the study period (Table 2.8). A few exceptions included a decrease in the number of retained spangled emperor from 3,105 in 2002/03 to 991 in 2007/08, and chinaman fish and stripey seaperch whose retained catches decreased by over 50% in the study period. The top five species retained accounted for only 31.6% of the total retained catch indicating a very diverse list of target species. For a number of species including barramundi, fingermark bream, mangrove jack, stripey seaperch and golden trevally, the number of fish released exceeded the number of retained in each year of the study. There was a decrease in the number of released unidentified emperors generally falling from 8,124 in 2002/03 to 222 in 2007/08. The number of stripey seaperch released was relatively stable throughout the study period until 2007/08 when it decreased by more than 50%. The number of unidentified trevally released increased from 818 in 2002/03 to 2,578 in 2007/08.

Table 2.5: Total number of fish retained and released per year for the South Coast Bioregion.

	Total number of retained species						Total number of released species					
Species name	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Bight redfish *	5,279	6,081	4,615	5,626	5,339	5,002	678	864	435	384	406	411
Swallowtail	1,681	2,477	1,815	2,105	1,986	2,016	18	22	64	45	304	267
Queen snapper *	1,126	1,044	662	790	965	716	44	41	24	14	25	26
Skipjack trevally	967	1,321	600	863	970	780	6	53	27	17	63	33
Breaksea cod	864	871	700	865	959	703	3	17	49	30	27	35
Leatherjackets, unidentified	445	300	421	831	676	483	31	4	43	1	33	1
Pink snapper *	433	998	445	599	1,042	509	40	70	34	74	96	101
Sea sweep	304	236	217	121	164	721	1	5	0	6	7	25
Samson fish *	303	268	176	342	239	214	73	38	28	9	5	34
Harlequin fish	200	148	151	135	107	83	0	0	4	3	1	0
Sergeant baker	155	118	73	133	75	35	172	46	35	0	1	0
Gurnards, unidentified	145	213	38	71	31	23	6	24	21	0	2	1
Western blue devil	126	150	69	49	67	55	3	0	1	0	3	7
Western Australian dhufish	111	141	84	96	108	73	2	23	16	3	0	1
Gummy shark	59	174	114	96	87	33	1	2	0	2	0	0
Australia herring *	23	497	720	580	755	659	8	254	205	603	309	212
Australian salmon *	20	39	58	71	102	132	0	23	49	87	83	182
Silver bream	10	238	156	97	142	66	3	0	27	9	13	2
King George whiting *	15	26	33	6	331	211	4	0	5	6	294	105
Western wirrah	46	45	9	7	5	2	0	3	0	0	0	1
Other species	716	680	451	526	572	433	145	281	255	569	429	436
Total	**13,028**	**16,065**	**11,607**	**14,009**	**14,722**	**12,949**	**1,238**	**1,770**	**1,322**	**1,862**	**2,101**	**1,880**
n - species	75	63	61	64	65	71	31	43	38	29	42	37

n - Denotes the number of distinct species * - Denotes indicator species for the bioregion – refer to Appendix B

Table 2.6: Total number of fish retained and released per year for the West Coast Bioregion.

	Total number of retained species						Total number of released species					
Species name	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Pink snapper *	10,756	12,119	14,188	10,094	12,923	11,371	5,877	6,713	4,570	4,018	6,062	4,071
Skipjack trevally	6,129	4,853	3,457	4,379	3,682	2,744	619	511	1,111	856	493	712
Sweetlip emperor	4,642	5,379	5,244	4,666	3,809	2,327	2,993	4,410	2,762	3,262	1,486	1,808
Breaksea cod	4,392	3,149	2,921	3,138	3,035	2,846	501	649	433	599	500	940
Western Australian dhufish *	4,348	3,296	3,107	3,230	2,670	2,557	2,389	1,440	1,312	1,224	1042	1,413
Baldchin groper *	2,828	2,464	2,339	3,278	3,582	2,279	929	969	683	836	804	2,199
Western rock lobster	2,273	1,550	1,704	1,610	1,080	1,310	916	852	663	424	238	524
Queen snapper	2,109	2,042	1,897	2,152	1,678	1,171	41	38	8	33	29	31
Samson fish *	1,865	1,605	1,427	1,051	649	462	4,189	4,868	5,047	3,902	2,604	1,811
Swallowtail	1,838	1,529	1,688	2,063	2,107	1,416	232	111	219	259	302	720
Sea sweep	1,587	1,258	1,624	1,455	1,720	1,992	211	188	239	246	230	395
Bight redfish	1,400	3,206	1,699	1,834	1,204	873	128	147	67	88	44	119
Sergeant baker	1,317	522	348	334	125	134	476	310	191	135	137	176
King George whiting *	1,183	341	317	299	313	303	117	2	1	13	40	5
Coral trout	1,063	576	411	597	568	387	246	61	37	223	101	77
Australian herring *	932	688	291	296	348	317	217	271	342	317	337	333
Yellow-eyed red snapper	522	896	1,224	1,049	866	391	144	136	258	169	176	316
Emperors, unidentified	916	662	603	360	1,515	1,573	704	402	785	383	734	459
Chinaman cod	640	554	349	337	549	624	469	339	65	187	301	261
Western foxfish	513	334	335	425	405	613	10	3	7	23	37	82
Whiting, unidentified *	1,137	220	184	374	137	106	179	56	12	73	75	109
Knife jaw	190	390	359	190	145	105	367	183	161	90	63	10
Other species	6,504	5,947	4,516	4,351	4,277	3,586	3,752	3,549	2,604	2,299	2,030	2,282
Total	**59,084**	**53,580**	**50,232**	**47,562**	**47,387**	**39,487**	**25,706**	**26,208**	**21,577**	**19,659**	**17,865**	**18,853**
n - species	175	169	153	146	136	143	146	132	122	120	113	111

n – Denotes the number of distinct species * - Denotes indicator species for the bioregion– refer to Appendix B

Table 2.7: Total number of fish retained and released per year for the Gascoyne Bioregion.

	Total number of retained species						Total number of released species					
Species name	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Pink snapper *	10,736	11,916	11,473	9,935	10,490	8,717	5,145	3,179	4,047	2,860	2,863	2,865
Sweetlip emperor	7,143	4,999	4,202	5,599	5,971	5,401	1,725	1,648	1,740	1,246	1,532	1,536
Spangled emperor *	6,201	4,339	3,452	3,721	3,718	3,434	1,472	596	263	303	340	398
Red emperor	2,861	2,428	2,153	2,952	3,285	2,650	490	371	212	244	182	128
Blue-lined emperor	1,641	1,043	1,188	1,487	1,138	742	797	298	328	652	680	193
Goldband snapper *	71	480	872	982	1,257	2,062	2	0	5	13	0	20
White-blotched rankin rockcod	1,406	868	783	1,344	1,703	1,270	61	21	20	34	78	83
Blue-spotted emperor	1,187	1,093	312	382	54	26	225	175	127	239	735	289
Chinaman cod	1,029	444	850	387	843	1,106	1,220	281	1,159	732	1,428	1,724
Emperor, unidentified	1,441	77	116	597	942	2,156	634	41	43	228	15	424
Trevallies, unidentified	486	256	153	252	432	316	88	91	83	129	87	104
Narrow-barred spanish mackerel *	476	339	180	176	214	309	97	88	87	80	60	112
Baldchin groper	464	331	368	310	389	520	82	38	49	49	97	140
Stripey seaperch	396	211	124	178	178	463	232	160	89	294	461	685
Robinson's seabream	367	262	378	676	742	814	1	0	3	4	5	6
Rosy jobfish	37	164	679	711	829	1,358	0	0	15	6	2	0
Estuary cod	245	132	55	76	138	111	24	22	7	16	43	29
Pearl perch	219	385	345	458	821	1,158	1	5	1	1	13	54
Cod, general	135	43	39	280	495	329	74	7	12	76	84	19
Other species	5,221	3,267	2,485	3,156	3,478	3,903	1,539	1,554	653	1,276	1,101	1,556
Total	**41,762**	**33,077**	**30,207**	**33,659**	**37,117**	**36,845**	**13,909**	**8,575**	**8,943**	**8,482**	**9,806**	**10,365**
n - species	139	128	123	130	131	117	124	110	95	99	97	106

n - Denotes the number of distinct species * - Denotes indicator species for the bioregion – refer to Appendix B

Table 2.8: Total number of fish retained and released per year for the Pilbara/Kimberley Bioregion.

	Total number of retained species						**Total number of released species**					
Species name	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Spangled emperor	3,105	2,634	2,597	2,653	1,781	991	426	353	336	460	423	273
Fingermark bream	2,035	2,177	2,699	2,269	3,094	2,832	3,531	3,258	3,770	3,480	4,303	5,040
Saddle-tailed seaperch	1,815	1,555	1,479	1,161	1,403	2,033	699	600	557	481	749	876
Emperors, unidentified	1,782	2,424	2,573	718	814	1,083	8,124	5,504	5,628	4,752	4,758	222
Mangrove jack	1,760	1,737	1,827	1,951	2,141	2,198	2,666	2,536	3,165	2,890	2,985	3,816
Barramundi*	1,495	1,170	1,631	1,401	1,880	1,364	4,206	2,659	3,702	3,140	4,118	2,908
Red emperor*	1,492	2,385	1,963	1,719	1,857	1,598	767	1,153	1,098	1,148	1,162	414
Blue-lined emperor	1,476	1,449	2,395	3,484	3,481	2,383	986	2,571	3,129	2,968	2,178	2,211
Stripey seaperch	1,428	942	1,574	1,544	1,332	622	5,179	5,447	4,956	6,743	6,456	2,766
Chinaman fish	1,312	861	871	792	719	582	213	245	111	205	78	166
Narrow-barred spanish mackerel*	1,162	1,028	1,394	891	547	648	735	839	1,385	1,029	1,362	1,103
Crimson seaperch	1,106	1,140	1,378	1,452	794	1,029	953	361	931	753	413	533
Golden trevally	772	942	989	464	368	169	1,780	1,992	1,874	1,802	1,963	1,486
Coral trout	686	1,066	1,182	893	964	750	429	842	1132	727	543	1,199
White-blotched rankin rockcod*	639	1,566	2,075	1,859	2,483	1,976	270	171	425	520	428	212
Estuary cod	545	397	487	366	515	447	1,283	1,329	1,985	1,975	1,642	1,736
Trevallies, unidentified	500	327	245	300	166	279	818	560	875	1,095	1,286	2,578
Oysters	376	719	790	400	804	847	0	0	0	0	0	0
Long-nosed emperor	372	613	769	685	638	559	70	100	215	314	331	194
Bluenose threadfin salmon *	315	379	370	348	631	381	452	493	622	569	788	629
Red seaperch	301	166	184	255	356	736	383	16	6	15	356	0
Mud crab, unidentified	291	481	566	353	341	257	65	37	146	122	78	104
Gold-spotted trevally	237	120	65	119	14	42	748	597	443	532	226	62
Brown mud crab	134	221	418	421	584	728	50	42	94	215	194	380
Moses perch	210	234	216	189	357	223	257	131	127	76	258	71
Queenfishes, unidentified	181	219	392	230	304	322	2,551	2,904	3,553	2,303	2,670	2,738
Blue-spotted emperor*	177	56	404	1,058	564	273	433	221	1,501	3,357	2,936	602
Giant trevally	128	124	174	198	95	53	2,325	3,580	3,541	1,974	2,602	2,458
Robinson's seabream	127	143	283	112	162	167	1	5	8	1	6	6
Catfish, unidentified	48	11	9	15	9	12	1,483	2,380	3,056	2,145	1,546	1,300
Other species	3,434	3,300	3,899	3,149	2,979	2,444	11,625	12,518	14,459	12,502	11,795	9,840
Total	**29,441**	**30,586**	**35,898**	**31,449**	**32,177**	**28,028**	**53,508**	**53,444**	**62,830**	**58,293**	**58,633**	**45,923**
n - species	145	151	147	141	136	128	195	202	217	200	203	164

2.4 DISCUSSION

The Western Australia charter boat industry conducted both extractive and non-extractive trips between 2002/03 and 2007/08 but with the majority (62.5%) of these trips being extractive. A study on the NSW charter boat fishery also found that 80% of the industry conducted extractive fishing trips (Steffe *et al.* 1999). Overall, charter operators in the Pilbara/Kimberley bioregion had the highest number of extractive trips of any Western Australian bioregion, this accounted for 81% of all trips in the bioregion. In the West and South Coast bioregions, approximately 60% of all trips conducted were extractive, compared to only 40% in the Gascoyne bioregion, highlighting the differences between the bioregions, variation in climatic zones and charter businesses.

The lower proportion of extractive trips in the Gascoyne bioregion may be primarily due to the presence of the Ningaloo reef, the largest reef system in the world that is found close to a continental land mass (Department of Environment and Conservation, 2010). Between March and May each year a large number of visitors converge on Ningaloo to experience a range of activities, including diving with whale sharks (Department of Environment and Conservation, 2010). In response, the charter industry in the Gascoyne bioregion utilises the surrounding environment, by offering non-extractive trips. In comparison, the highest proportion of extractive trips (81%) observed in the Pilbara/Kimberley bioregion may be the result of its remote isolation and distance from major towns. With over 50% of all West Australian registered recreational boats based in the Perth Metropolitan area, charter boat operators working in the Pilbara/Kimberley bioregion provide more appropriate facilities for long-term accommodation and overnight stays, due to the distances between major towns, reducing the ability to operate daily services, as well as removing the burden of driving and towing a recreational boat over long distances (Department of Planning and Infrastructure, 2007). In comparison, the balance between extractive and non-extractive trips in the South and West Coast bioregions were closer to equity with 62% and 61% respectively, slightly in favour of extractive trips. This highlights the different ranges of charter businesses and services operating in these bioregions. In NSW, the charter industry which is has a similar climatic zone as the West and South Coast bioregions, recognised that non-extractive charter trips were extremely important to the economic viability of their businesses (Steffe *et al.,* 1999) as they did not rely solely on extractive trips all year round.

Obtaining data which are comparable and concurrent across all bioregions and all sectors, for certain species is an ongoing challenge facing fisheries managers. For example, the estimated total biomass (tonnage) of fish retained for the charter industry in Western Australia in 2007/08 was 276 tonnes, whereas in the same year the commercial sector landed 23,694 tonnes (State of the Fisheries report 2008/09), but the state wide recreational catch is unknown. The recreational sector is one of the hardest for which to obtain total catch estimates, since the survey techniques used have exceptionally high running costs and therefore cannot be completed on an ongoing basis, which means the recreational sector's catch and effort levels are often not monitored for long periods of time. In 2000/01 the National Recreational and Indigenous Fishing Survey, was the first Australian wide survey aimed at estimating the each States and Territory total recreational catch and effort. Included in this were estimates for the charter industry, in Western Australia the charter industry accounted for 2% of the total scalefish catch in the State, whilst the recreational sector accounted for 25% (Henry & Lyle, 2003). Since then, there has been an increase in the proportion of catch for some species taken by the charter boat industry in Western Australia. Within the West Coast and Gascoyne bioregions respectively the charter industry accounted for 5% and 6% of the total pink snapper catches in 2005/06 and 2005 (St John & Johnson, 2007, Jackson & Lai 2006). Pink snapper is the most commonly retained species by the charter industry which accounted for 17.8% of the total catch over the study period. Whilst there is some evidence of an increase in the charter industries proportion of pink snapper catch, overall it still accounts for a low proportion of the total catch in comparison to the recreational and commercial sectors.

The monthly average for catch, effort and catch rate information for each bioregion demonstrates that the charter industry was strongly influenced by seasonal patterns. Obviously, clients taking part in charter activities would prefer to undertake them during optimum weather conditions. In the South and West Coast bioregions these peaks occurred during the summer months (November to February) whilst in the Gascoyne and Pilbara/Kimberley these peaks occurred during the winter months (May to August). While the catch, effort and catch rates fluctuate as a consequence of seasonal influences, the patterns have remained relatively consistent throughout the study period, excluding the Gascoyne bioregion, where catch rates showed an increase over time. This was likely the result of a more stable fishing fleet, compared to other bioregions and increased efficiency, such as knowledge on fishing "hotspots" marked by global positioning system (GPS) from prior fishing events. Over the study period, the number of clients fishing in the Gascoyne bioregion decreased (Figure 2.6) but the catch remained stable, so even with less clients fishing, the effective ability to catch the same level of catch may indicate an increase in efficiency. The stability in the charter industry in Gascoyne bioregion was evident with 86% of the catch accounted by the top ten fishing operators, of which seven of the same charter operators remained in the top ten throughout the study period. In addition, over 60% of all trips in the bioregion are non-extractive, whilst in the other bioregions, the majority was extractive, thus reducing competition for fish stocks among operators. In other studies conducted on inflated catch rates in commercial fleets, the adoption of new technologies such as GPS, more powerful boats and mechanical reels resulted in increases in efficiency, termed technology creep (Marriott *et al.,* 2011). These factors can result in misleading results in commercial sector catch rates analyses, as effort reduction can lead to a perceived increase in catch rates (Wise *et al.,* 2007). Whilst these results depict the effect of increases in technology to commercial fishing fleets, it may be assumed that technology advances would also apply to the recreational sector and charter industry as they compete for fish stocks. However this is only speculative as no known research has been conducted on the efficiency effect on the recreational sector.

The number of charter fishing licenses issued by the DoF compared to the number of active fishing operators per bioregion over the study period has highlighted an issue and has management implications, which if not resolved may ultimately affect the sustainability of the both the industry and fish stocks. On average over the study period the number of inactive operators ranged between 41.4% and 54.7% in the Pilbara/Kimberley and Gascoyne respectively. This high proportion of inactive licenses equates to a high level of latent effort in the charter industry of Western Australia. Not all charter operators who are issued with licenses for extractive activity utilise them as such, instead conduct activities such as whale watching, this is at the discretion of the operators. However, all operators licensed with a FTOL have the capacity to switch to fishing activities without any administrative barriers. In addition, of the active fishing charter boat operators, 31% reported between only one and ten fishing trips each financial year, this opens ups the possibility for the capacity of latent effort to increase further. The management implications for latent effort, for both the sustainability of fish stocks and the industry has substantial consequences, as uncontrolled increases in effort can have devastating effects on fish stock, the ecosystem and the industry (King, 2007). According to Walters (2004) the latent effort for some Australian fisheries, was more than sufficient to cause severe overfishing should that latent effort be exercised.

A few operators account for a large proportion of total catch taken in all bioregions (Figure 2.4), which could have some implication for management. In the South Coast and the Gascoyne bioregions, a large proportion of the total retained catch was accounted for by the top ten operators. In contrast, the proportion was considerably lower in the West Coast and Pilbara/Kimberley bioregions. The reason for the difference between bioregions is not clear, however it may be the result of the number of operators licensed in each bioregion. This study showed that a bioregion with a high number of licenses resulted in a lower proportion of the top ten accounting for the catch, suggesting increased competition for catch and clients.

Catch data for the charter industry between 2002/03 and 2007/08 showed variability in a variety of different species across the bioregions. Even though the charter industry accounts overall for a small proportion of the total catch across all sectors, variations in their catches of certain species can provide important indicators of current stock status and may provide the necessary triggers to warrant further investigation. The majorities of the species retained and released by the charter industry are demersal scalefish, or bottom dwelling species and in all bioregions some of the key indicator species (refer to Table 2.5-2.8 and Appendix B) represent a high proportion of the charter industries catches. During the study, catches of species such as goldband snapper and rosy jobfish in the Gascoyne bioregion almost doubled. Significant shifts in catches were also evident in the number of baldchin groper released in the West Coast bioregion, where a 50% increase in released baldchin groper occurred in one year. Given the mortality rate for baldchin groper is extremely high most of the released fish would not survive (Lenanton *et al.,* 2009). This is an important indicator species and should be monitored to ensure localised depletion does not occur. The key species taken in each bioregion were similar over the study period, even without significant variations in catches, this quantitative information provides a benchmark of species diversity and levels of catches to both managers and researchers.

Information on target species was and is still not collected through the logbook program. However, using patterns in the catches over time, assumptions could be made that certain species are targeted within each bioregion. Catch trends suggest that the following species are examples of some of the key target species; pink snapper, bight redfish, barramundi, spangled emperor and fingermark bream. Within the charter industry, targeted species are likely to be strongly influenced by clients' needs, wants and expectations. The target species could change almost daily if an operator adjusted his fishing practices to fit with his clients' expectation, for example, in one trip an operator may target game fish such a marlin and the next it might be barramundi. This could be influenced by the popularity of species, as they move in and out of the preferred species to catch. To understand these trends further, targeted species information would need to be recorded in the logbook, so trends could be monitored over time.

The number of species released provides essential information on by-catch data, as well as provide an indicator of strong cohort recruitment for a species if large quantities of undersize fish are released. However, what is not known is the associated long-term impact releasing high volumes of fish has on species. Charter boat operators are not asked in their logbook to indicate why a fish was released, such as undersize or an undesirable species. Without this level of information and with unknown mortality rates of all released fish, the direct impact on fish stocks remains unclear, and therefore, has potential implications for management. Biological information, together with research, can provide data on survival rates for species, however, this kind of information is not currently available for all species. Research conducted on key species such as pink snapper and dhufish revealed that mortality of the former species can be as high as 69%, while that for dhufish caught at depths greater than 45m it was 86%, usually caused by barotrauma (St.John & Syers, 2005 and Lenanton *et al.,* 2009). Mortality rates over 20% are considered to be high (Muoneke & Childress, 1994). The number of fish released across all bioregions, but particularly in the Pilbara/Kimberley, raises some concern as it is the only bioregion where the number of fish released was higher than those retained. It seems from these results that charter operators in the Pilbara/Kimberley bioregion undertake more catch and release, compared to other bioregions. It is a common misconception among recreational fishers that if fish are released, their populations will not decline (Policansky, 2007). Many of the species caught in the Pilbara/Kimberley have unknown survival rates, so the direct impact cannot be deduced. If one assumes the post-release mortality rates to be high, then the associated impact that charter fishing has on these fish stocks could also be high. Future considerations for the DoF, should include scope for the reasons for releasing fish and perhaps the condition of the fish at the time of release.

CHAPTER 3

SPATIAL ASSESSMENT OF CHARTER BOAT FISHING IN THE WEST COAST BIOREGION

3.1 INTRODUCTION

Fisheries management often places restrictions on the quantity of fish caught, gear and size limits, or alternative management controls such as spatial and temporal closures (King, 2007). The development of these management strategies typically relies on catch and effort data from the fisheries, however these data are often summarised over large areas and times (Fletcher & Santoro, 2009), thereby removing spatial and temporal resolution that can be useful for understanding patterns in fisheries, which can be applied to management. A spatial and temporal study on a prawn and scallop fishery of Western Australia showed that geostatistical modeling can improve the management of these fisheries ensuring optimum sustainable exploitation of the valuable fish stocks at both a temporal and spatial scale (Mueller *et al.*, 2008). The knowledge of spatial distribution and characterisation of a species is essential for a better understanding the population's interaction with the environment and their habitat (Monestiez *et al.*, 2005). With the majority of fisheries research focused on temporal variability of fish populations, an understanding of the spatial variability in fisheries can provide important information to management when assessing the marine ecosystem as a whole (Ciannelli *et al.*, 2008).

Geostatistical modeling aims to provide quantitative descriptions of natural variables distributed in space, time or both, and is applied well to variables that are often sampled sparsely or exhibit immense complexity (Chilès & Delfiner, 1999). This approach is designed to study the spatial characteristics of one or more variable(s), and can be used to investigate how the spatial structures of those variables change over time (Rivoirard, 2000). While it is a technique that has been developed for mineral resource estimation (Moura & Fernandes, 2008), it was first applied to fisheries management by estimating the spatial distribution of shellfish stocks (Conan 1985). Since then, geostatistical modeling has provided managers with another platform for exploring the associated impacts that commercial and recreational fishing pressures place on fish stocks (Moura & Fernandes, 2008).

As fish stocks come under increased pressure from both commercial and recreational sectors, there becomes a stronger need to ensure that management arrangements are economically variable as well as sustainable. Thus, the adoption of relatively new techniques, such as geostatistics, provides managers with another tool for making better informed decisions. Within the West Coast bioregion in Western Australia, Department of Fisheries (DoF) Managers in recent years have had to make significant changes over a short period of time to both recreational (including charter) and commercial fishing practices, as demersal fish stocks were significantly depleted (Wise *et al*., 2007). Within each bioregion, the DoF has selected key ‘indicator’ species as a way of prioritising the stocks that should be monitored and assessed (DoF, 2011). Identification of indicator species, through a risk-based approach, is based on the species’ vulnerability to fishing, whether it is targeted stock by commercial and recreational sectors; and its economic and cultural value (Lenanton *et al.* 2006, DoF 2011). Indicator species represent the populations of all stocks classified within an assemblage of species, for example pelagic or demersal, refer to Appendix B.

The current strategies implemented by the DoF aim to efficiently manage the diverse array of WA finfish species and their associated fisheries, by grouping species into species assemblages based on their distribution, life history traits and methods of capture (Hourston & Johnson, 2009). The approach recognises that it is not possible to study or even directly manage every species captured in a multispecies fishery, and uses the assumption that if the indicator stocks are at acceptable levels then the whole assemblage should be in an acceptable state. If, however, one or more indicator species is found to be at an unacceptable level, the entire assemblage would require attention (Wise *et al.*, 2007).

In the West Coast bioregion, the level of exploitation of the three key indicator species for demersal stocks, the Western Australian dhufish (*Glaucosoma hebraicum*), pink snapper (*Pagrus auratus*) and baldchin groper (*Choerodon rubescens*), were considered to be above international benchmark standards (Wise *et al.*, 2007). These bench-mark standards, based on stock biomass and fishing mortality, define action triggers if they reach a certain threshold (Wise *et al.,* 2007), and in the case of those three species, indicated that their stocks were being currently being over fished (Wise *et al*., 2007).

The biology and spatial distribution of these indicator species make them particularly vulnerable to overfishing (Wise *et al.,* 2007). Both the recreational (including charter) and commercial sectors catch these species typically by line methods. Dhufish are endemic to the southwest coast of WA, are long lived (>40 years) and slow growing with low productivity (Wise *et al.,* 2007). Whilst, pink snapper have a wider distribution stretching from the Gascoyne bioregion to the South Coast, are also long lived (>30 years) but it is their spawning behaviour that makes them easy to target as they aggregate in large assemblages at the same time and place each year (Wise *et al.,* 2007). Baldchin groper are also endemic to WA and are most abundant in the Abrolhos Island region (Wise *et al.,* 2007).

The charter boat industry of Western Australia has been providing comprehensive catch and effort data to the DoF since September 2001, when the logbook system was implemented (DoF, 2000). Analysis of these data presented in Chapter 2, showed that the West Coast bioregion for the charter industry was the busiest in Western Australia, accounting for the highest number of clients, fishing trips and active charter operators. Catch data also highlighted that pink snapper, dhufish and baldchin groper accounted for a high proportion of the overall catch for the charter industry as most fish stocks targeted by the industry are demersal scalefish. In addition, these indicator species provide an estimated $4 million annually to Western Australian economy (Australian Commodity Statistics, 2009). As a result of the level of exploitation of the three key indicator species and the associated role that the charter industry has had on these stocks, it was appropriate that detailed analyses were undertaken to examine spatial and temporal trends in the fisheries using geostatistical techniques.

The aim of this chapter is to evaluate the spatial structure of the charter industries overall catch rates between 2002/03 and 2007/08, as well as three indicator species pink snapper, dhufish and baldchin groper, using various geostatistical techniques to determine how the spatial structure of catch rates has changed over time. The spatial analyses will reduce some of the knowledge gap that currently exists with regards to detailed information about the charter industry of Western Australia pertaining to the movement of the fishing fleet, and will assist in providing information to fisheries management, which may in turn facilitate the long-term sustainability of fish stocks and the industry.

3.2 DATA PREPARATION

The catch rate information used in this chapter was derived from the charter logbook program, administrated by the DoF. The catch and effort data were taken from extractive activities conducted by licensed Fishing Tour Operators, Restricted Fishing Tour Operators and Aquatic Eco-Tourism licence holders (Aquatic Eco-Tourism were only included in the 2002/03 and 2003/04 years as the ability to fish using this license category was changed, refer to Chapter 1). An extractive activity refers to any attempt (whether successful or not) to extract, catch and/or hook any aquatic species (refer to the glossary of words, Chapter 1). This study specifically considers logbook data by financial years for the time period 1st July 2002 to the 30th June 2008 in the West Coast bioregion (Figure 3.1). Analyses were completed at the bioregional level, and subsequently disaggregation into the northern and southern zones, noting some data was removed after the split because of the influence of distances between catch rates (Figure 3.1 and 3.2). The boundary line for the zones was set due to broad spatial-scale patterns in catch rates and it is also the northern boundary of the metropolitan zone used by DoF management and research within the West Coast Bioregion (Wise *et al*., 2007).

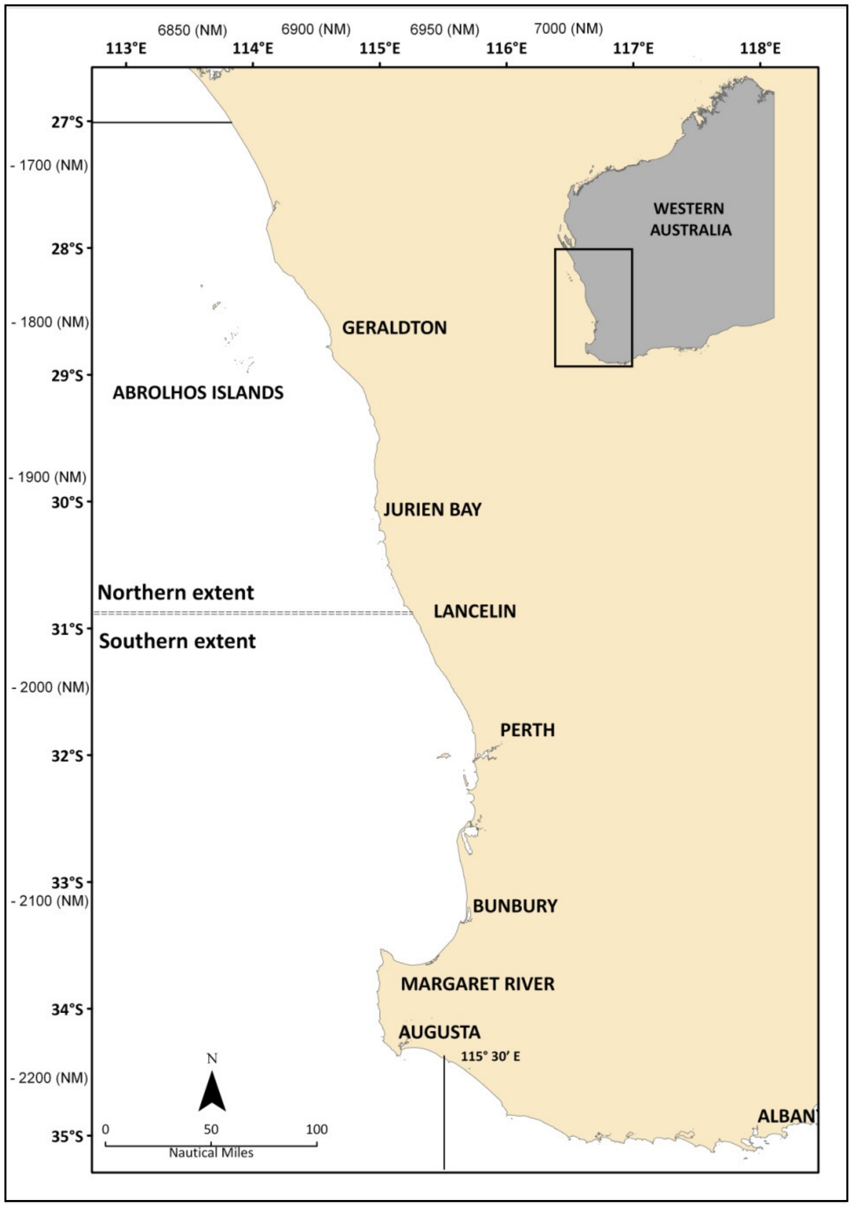

Figure 3.1: West Coast bioregion, study area.

The catch and effort data used in these analyses were checked for completeness, and any missing and/or incomplete returns specifically in relation to fishing block locations were omitted from these analyses. Data from catches in rivers and/or inland locations were also excluded, as the focus of this study was the marine environment. Charter operators report the location for each activity using 5 by 5 nautical mile (nm) block locations. An operator selects a block location by where they spend the most amount of time undertaking an activity, in this case fishing. Appendix C includes logbook instructions provided to Charter operators. For geostatistical analysis, each block location was converted to a latitude and longitude location, by calculating a centroid (central point) location for each block. This was done using ArcGIS version 9.3.1.

Fishing effort was calculated and measured by the total number of clients fishing (*F*), from extractive trips, e.g. the number of clients fishing, the number of clients diving (extractive trips only) and the number of clients snorkeling (extractive trip only). Time spent fishing was not included in effort calculations as approximately 25% of returns had missing fishing times. The majority of missing entries for fishing duration occurred in the earlier years of the study, as operators adjusted to completing logbooks for the first time. Catch was calculated separately, and was the total number of retained individuals (*C*) per 5 × 5 nm block. Catch rates (*CR*) were calculated by dividing the total number of retained individuals per year in a 5 × 5 nm (*C*) by the total effort (*F*) (number of clients actively fishing) in that block.

$$CR = {}^{C}/_{F}$$

Targeted species information is not recorded in the charter logbook program, so the catch rates for the key indicator species, dhufish, pink snapper and baldchin groper, were again calculated as the ratio of the total number of each species retained in a block and the total effort (number of clients actively fishing) in that block. In some cases high catch rate values (greater than 5.0) occurred in the data set. However since they were shown to be accurate (as reported by the charter operators), they were retained in the analysis, however high catch rates values should be interpreted with caution. Outliers defined as values greater than or less than one and half times the interquartile range, where removed from the analysis. Biological distribution of these three species varies according to habitat, thus, spatial analysis was limited to their preferred habitat region (Lenanton *et al*., 2009): Dhufish in the southern extent of the West Coast bioregion, baldchin groper in the northern extent of the region and pink snapper in both the north and south (Figure 3.1).

The spatial distribution of catch rates in Figure 3.2 (total catch 5 x 5nm/total effort 5 x 5nm) in each financial year was presented using ArcGIS version 9.3.1. The scales applied to the kriged (refer to Figures 3.9 to 3.15) spatial maps were calculated from the deciles of the estimates for the 6-year period. A hot spot is defined as the highest catch rate estimate for each spatial map (indicated by the colour red).

3.2.1 SPATIAL CORRELATION

Tjøstheim's index A of spatial association measures the similarity between the distributions of values of two variables defined on the same set of locations in 2D space. It compares two variables $F = F(x, y)$and $G = G(x, y)$ observed over the same n locations and ranked from 1 to n, and $(x_F\ (i)), (y_F\ (i))$ and $(x_G\ (i)), (y_G\ (i))$ denote the location of rank i on F and G, and where the co-ordinates of the locations are standardised (Tjøstheim, 1978):

$$\sum_{i=1}^{n} x_F\ U(i) = \sum_{i=1}^{n} x_G\ U(i) = \sum_{i=1}^{n} y_F\ U(i) = \sum_{i=1}^{n} y_G\ (i) = 0$$

and

$$\frac{1}{n}\sum_{i=1}^{n} x_F^2\ (i) = \frac{1}{n}\sum_{i=1}^{n} x_G^2\ (i) = \frac{1}{n}\sum_{i=1}^{n} y_F^2\ (i) = \frac{1}{n}\sum_{i=1}^{n} y_g^2\ (i) = 1$$

Tjøstheim's Index A is a numerical measure to check if the position of the location ranked i for variable F is the same as, or close to the location ranked i for the second variable G, it is given by (Tjøstheim, 1978):

$$\mathrm{A} = \sum_{i=1}^{n} [\ x_F\ (i) x_G\ (i) + y_F\ (i) y_G\ (i)]$$

and Var (A) = $(1 + r^2_{xy})/\ (2(n-1))$, where r_{xy} is the Pearson correlation coefficient between the set of x and y coordinates over the n locations. The test statistic used for testing the null hypothesis, that there is no spatial association between the variables F and G, is calculated as (Tjøstheim, 1978):

$$z = \frac{A}{\sqrt{var\ (A)}}$$

with the null hypothesis being rejected at level of significance ∂ if $z > z_{\partial/2}$ or $z < z_{\partial/2}$ thus ∂ at 0.05 significance $z_{\partial/2} = \pm 1.96$ (Mueller *et al.*, 2008). Tjøstheim's indices with a value close to 1 indicate a strong spatial association between locations and values closer to -1 indicate disassociation within adjacent years from the same location (Dickson, 2007). Values close to 0 indicate no association.

Spearman's rank correlation coefficients were also calculated to measure the statistical dependence between two variables, this calculation always returns a value between +1 and −1 inclusive, and was done together with Tjøstheim's index A calculation using Microsoft excel. These two techniques provide another way of assessing the spatial relationship between variables with Tjøstheim's index A providing a direct comparison between subsequent years.

3.2.2 GEOSTATISTICS

Geostatistics provides a set of statistical tools for incorporating the spatial (and temporal) coordinates of observations in data. Geostatistics is largely based on the concept of the random function, whereby a set of unknown values is regarded as a set of spatially dependent random variables (Goovaerts, 1997). The uncertainty about an attribute value at any particular location $\mathbf{u}$ is modeled through the set of possible realisations of the random variable at that location.

The random function concept is a construct that was introduced to overcome problems associated with the inability to repeat measurements. The random function is defined as a set $\{\mathrm{Z}(\mathbf{u}),\ \mathbf{u} \in \mathrm{A}\}$ of usually dependent random variables $Z(\mathbf{u})$, ($\mathrm{Z} = CR$) one for each location $\mathbf{u}$ in the study area A (Goovaerts, 1997). To any set of N locations $\mathbf{u}_\kappa$, $\kappa = 1, \ldots, N$ corresponds a vector of N random variables $\{\mathrm{Z}(\mathbf{u}_1), \ldots, \mathrm{Z}(\mathbf{u}_N)\}$ that is characterised by the N - variate or N - point cumulative distribution function (Goovaerts, 1997). It is the entirety of all possible *N*-variate distributions constructed from the random function that describes the spatial law of the random function. Particularly importance for the techniques applied in this thesis, are bivariate distributions and their moments. The main structural tool used in modeling random function is the semivariogram (Goovaerts, 1997). Semivariograms are used to construct a model for the spatial dependence of the data. Using the models derived from the experimental semivariograms, kriging estimates are generated for the unobserved locations and this is done via moving neighbourhoods, as data close to the location whose value is to be estimated are deemed to have greater importance than those further away. The resulting estimates can be used to construct a smoothed spatial map.

The experimental semivariogram is defined as the sum of half the average squared differences between the attribute values of every data pair separated by the distance vector $\boldsymbol{h}$ (Goovaerts, 1997).

$$\gamma(\boldsymbol{h}) = \frac{1}{2\mathrm{N}(\boldsymbol{h})} \sum_{\alpha=1}^{N(\boldsymbol{h})} [z(\mathbf{u}_\alpha) - z(\mathbf{u}_\alpha + \boldsymbol{h})]^2$$

where [z ($\mathbf{u}_\alpha$) –z ($\mathbf{u}_\alpha + \boldsymbol{h}$)] is an $\boldsymbol{h}$ increment of the attribute z and $N(\boldsymbol{h})$ is the number of pairs of data locations separated by the lag vector $\boldsymbol{h}$ (Goovaerts, 1997). The experimental semivariogram measures how values of the random function differ as the distance between locations increases. When the variogram does not vary with direction, it is said to be isotropic. It is then a function of the modulus of the vector $\boldsymbol{h}$, namely of the distance between locations. Otherwise, the variogram is anisotropic (Rivoirard, J., et al., 2000). In the models below a and h denotes the range and distance from the origin respectively.

The following models, were used in the fitting of the associated experimental semivariograms. In all cases a spherical model was chosen, as it was the best fit that captures the features in the experimental semivariograms. Spherical model are commonly used in geostatistical analysis of biological populations because its structure increases at the origin and then stablises, this corresponds with spatial variation that is often observed in nature (Kleisner *et al.,* 2009).

Nugget: $\gamma(h) = \begin{cases} 0 & if\ h = 0 \\ 1 & \text{otherwise} \end{cases}$

Spherical model:

$$\gamma(h) = \begin{cases} \frac{3h}{(2\alpha)} - \frac{h^3}{(2\alpha^{3)}} & if h \leq \alpha \\ 1 & otherwise \end{cases}$$

(Geovariances, 2005).

Ordinary kriging is a multiple linear regression estimation method based on moving windows and is the most common type of kriging (Rivoirard, J *et al*., 2000). Kriging was chosen for this study as it's the best linear unbiased estimator (Goovaerts, 1997). Ordinary kriging is used to estimate the expected value of a random variable, *Z*, at one or more unsampled points. Kriging incorporates the semivariogram model described previously and uses it as a measure of distance. In general an ordinary kriging estimate of the attribute at the unsampled location **u** is:

$$Z^*_{OK}(\mathbf{u}) = \sum_{\alpha=0}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})[\mathrm{Z}(\mathbf{u}_\alpha) - m(\mathbf{u}_\alpha)] + m(\mathbf{u})$$

where $Z^*_{OK}(\mathbf{u})$ and $\lambda_\alpha(\mathbf{u})$ denote the ordinary kriging estimate and the ordinary kriging weight corresponding to $\mathbf{u}_\alpha$ at location $\mathbf{u}$ and $m(\mathbf{u})$ denotes the unknown mean, $n(\mathbf{u})$ denotes the number of sample locations within the search window at **u**. For ordinary kriging the local mean $m(\mathbf{u})$ is assumed to be unknown, but constant within a local neighbourhood and so needs to be filtered from the equation. Thus it is assumed that

$$m(\mathbf{u}_\alpha) = m(\mathbf{u}), \alpha = 1, \ldots, n(\mathbf{u})$$

and since

$$Z^*_{OK}(\mathbf{u}) = \sum_{\alpha=0}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})\mathrm{Z}(\mathbf{u}_\alpha) + \left[1 - \sum_{\alpha=0}^{n(\mathbf{u})} \lambda_\alpha(\mathbf{u})\right] m(\mathbf{u})$$

in order to filter the unknown mean from the equation it is required that

$$1 - \sum_{\alpha=0}^{n(\mathbf{u})} \lambda_{\alpha}\ (\mathbf{u}) = 0$$

The ordinary kriging system is obtained by minimizing the error variance associated with this estimator and consists of $(n(\mathbf{u}) + 1)$ linear equations with $(n(\mathbf{u}) + 1)$ unknowns, the $n(\mathbf{u})$ weights $\lambda_{\alpha}^{OK}(\mathbf{u})$ and the Lagrange parameter $\mu_{OK}(\mathbf{u})$ which accounts for the constraint on the weights:

$$\begin{cases} \sum_{\beta=1}^{n(\mathbf{u})} \lambda_{\beta}^{OK}(\mathbf{u})\, \gamma\left(\mathbf{u}_{\boldsymbol{\alpha}} - \mathbf{u}_{\boldsymbol{\beta}}\right) - \mathrm{u}_{OK}(\mathrm{u}) = \gamma(\mathbf{u}_{\boldsymbol{\alpha}} - \mathbf{u}) \\ \sum_{\beta=1}^{n(\mathbf{u})} \lambda_{\beta}^{OK}\ (\mathbf{u}) = 1 \qquad\qquad \alpha = 1, \ldots\ldots, n(\mathbf{u}) \end{cases}$$

(Goovaerts, 1997).

3.3 RESULTS

3.3.1 SUMMARY STATISTICS

Overall, the spatial area of fishing grounds for the charter industry for all species in the West Coast bioregion has changed between 2002/03 and 2007/08 (Figure 3.2). Higher catch rates greater than 2.89, occurred more frequently in the northern extent of the bioregion compared to the south. The number of locations within the study area where fishing took place decreased between 2002/03 and 2007/08 (Table 3.1) and the number of medium to high catch rate locations (between 0.47 and >2.89) has also reduced, particularly in the southern extent of the bioregion (Figure 3.2).

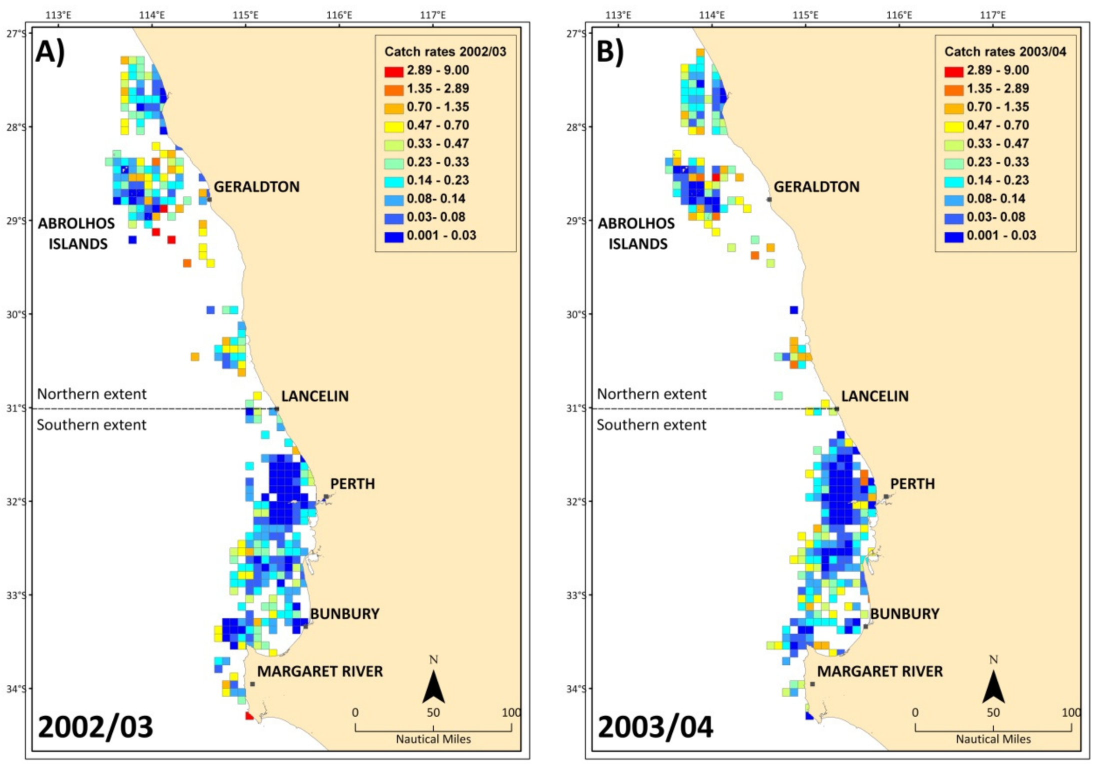

Figure 3.2: Catch rate spatial maps for the charter boat industry in the West Coast bioregion, 2002/03 (A), 2003/04 (B), 2004/05 (C), 2005/06 (D), 2006/07 (E) and 2007/08 (F).

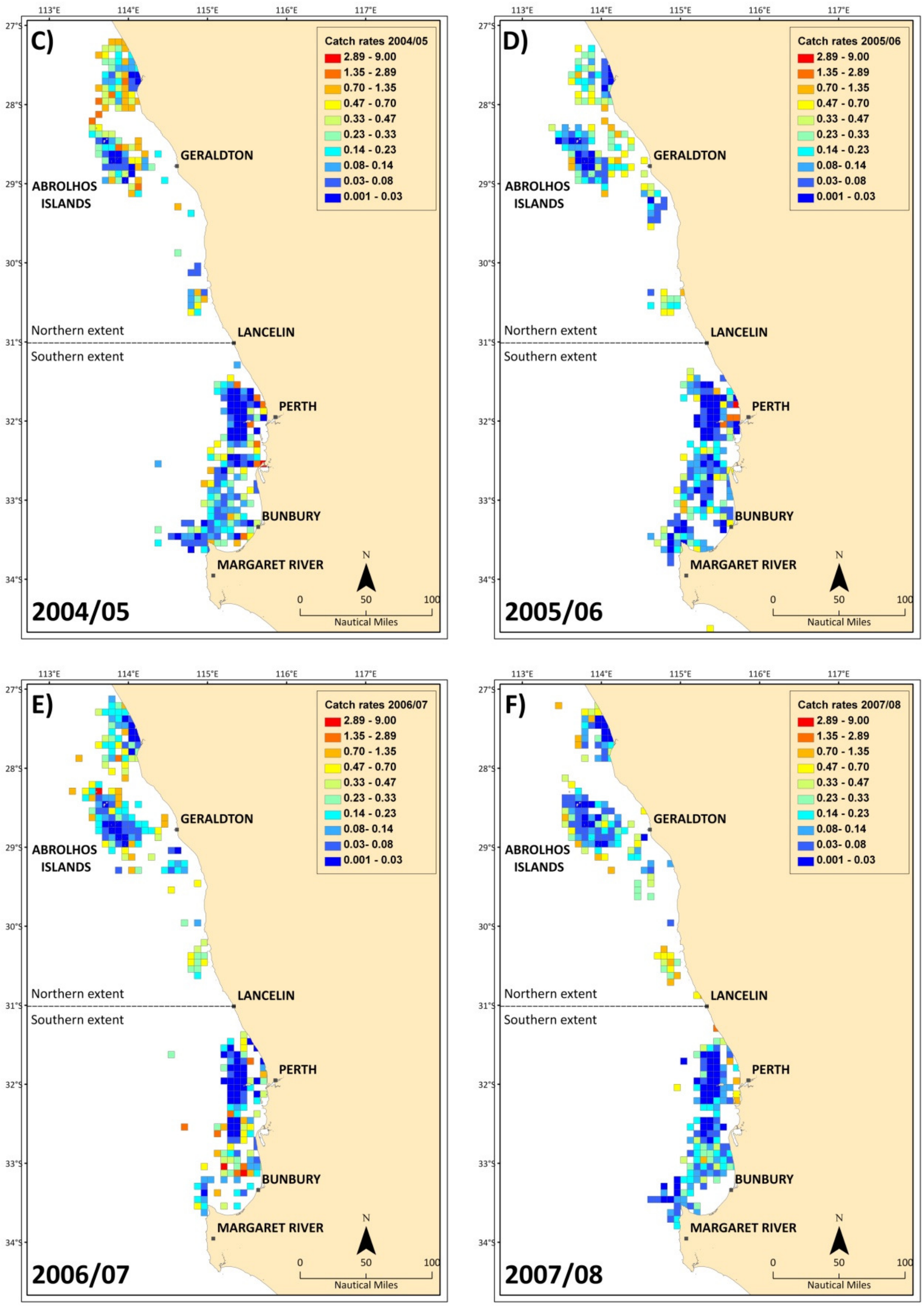

Figure 3.2 continued: Catch rate spatial maps for the charter boat industry in the West Coast bioregion, 2002/03 (A), 2003/04 (B), 2004/05 (C), 2005/06 (D), 2006/07 (E) and 2007/08 (F).

The number of block locations where fishing activity was recorded for all species in the West Coast bioregion decreased from 341 in 2002/03 to 278 in 2007/08 (Table 3.1). In comparison between the northern and southern extents of the West Coast bioregion, the number of block locations where fishing activity was recorded for all species was greater in the south. In the north the highest count was 137 in 2006/07, whilst in the south, the highest count was 194 in 2002/03, a 29% difference (Tables 3.1, 3.2 and 3.3). The mean catch rates for all species in the West Coast bioregion fluctuated, however the range of variation in the mean catch rate was less than 0.5, which also was evident in the northern extent of the bioregion. In the southern extent the fluctuation of the mean catch rate was smaller in the first five years, where there was an overall decline, this was followed by a sharp decrease in 2007/08 (Tables 3.1 to 3.7).

Throughout the bioregion and across species the mean catch rates were higher in the north than in the south. For the overall catch rates it was lowest in 2004/05, which was also the case for the northern extent of the bioregion. The coefficients of skewness for the north are usually smaller than those for the south. The coefficients of variation for the overall catch rates varied from between 0.43 and 0.88 and were smaller in the north than in the south of the West Coast bioregion.

The number of block locations where fishing activity was recorded for pink snapper decreased in the south from 158 in 2002/03 to 84 in 2006/07, but increased to 99 in 2007/08, whilst in the north it was consistent across all years, with each year above 100 (Table 3.4 and 3.5). There was a decrease in the number of block locations where fishing activity was recorded for dhufish in the south, whilst the number of locations where baldchin groper was recorded in the north was stable (Table 3.6 and 3.7). The mean catch rate for Dhufish was lowest in 2007/08, whilst for pink snapper the lowest mean catch rate was in 2005/06 in the south of the bioregion and for baldchin groper the lowest mean catch rate occurred in 2004/05. All catch rate distributions are strongly positively skewed for all years and species for which data were collected (Tables 3.1 to 3.7). The strength of the skewness varies from year to year.

Table 3.1: Summary statistics, annual catch rates for all species (total catch 5 x 5nm/total effort 5 x 5nm) in the West Coast bioregion.

All species	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Count	341	303	303	297	271	278
Minimum	0.09	0.13	0.14	0.16	0.01	0.02
Maximum	11.67	9.7	9.58	11.75	15.35	10.13
Mean	2.318	2.35	2.452	2.235	2.492	2.078
Standard deviation	1.699	1.51	1.493	1.479	1.647	1.442
Coefficient of variation	0.733	0.643	0.609	0.662	0.661	0.694
Skewness	2.214	1.9	1.359	2.792	2.566	1.705

Table 3.2: Summary statistics, annual catch rates for all species (total catch 5 x 5nm/total effort 5 x 5nm) in the north of West Coast bioregion.

All species - north	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Count	125	103	117	125	137	120
Minimum	0.09	0.14	0.5	0.33	0.21	0.2
Maximum	9.67	9.7	7	6.13	9.3	10.13
Mean	2.763	2.974	3.182	2.567	2.946	2.634
Standard deviation	1.778	1.578	1.436	1.103	1.511	1.455
Coefficient of variation	0.643	0.531	0.451	0.43	0.513	0.552
Skewness	1.58	1.953	0.66	0.985	1.344	1.795

Table 3.3: Summary statistics, annual catch rates for all species (total catch 5 x 5nm/total effort 5 x 5nm) in the south of the West Coast bioregion.

All species - south	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Count	194	190	171	160	117	140
Minimum	0.12	0.13	0.14	0.16	0.01	0.02
Maximum	11.67	9.29	9.58	11.75	15.35	6.67
Mean	1.986	1.931	1.917	1.92	1.868	1.321
Standard deviation	1.532	1.233	1.281	1.649	1.644	0.783
Coefficient of variation	0.772	0.638	0.668	0.859	0.88	0.593
Skewness	3.171	2.224	2.868	3.792	4.989	2.608

Table 3.4: Summary statistics, annual catch rates for pink snapper (total catch 5 x5nm/total effort 5 x 5nm) in the north of the West Coast bioregion.

Pink snapper - north	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Count	107	101	109	115	125	113
Minimum	0	0.067	0	0	0	0.1
Maximum	8.667	4.0	3.6	1.85	6.0	6.25
Mean	0.759	0.846	1.043	0.7	1.021	0.949
Standard deviation	0.983	0.694	0.707	0.423	0.906	0.759
Coefficient of variation	1.295	0.82	0.678	0.604	0.887	0.799
Skewness	5.397	2.568	1.43	0.563	2.731	3.577

Table 3.5: Summary statistics, annual catch rates for pink snapper (total catch 5 x5nm/total effort 5 x 5nm) in the south of the West Coast bioregion.

Pink snapper - south	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Count	158	154	151	120	84	99
Minimum	0	0	0	0	0	0
Maximum	3.0	1.73	3.056	1.313	3.616	1.50
Mean	0.367	0.338	0.416	0.271	0.516	0.302
Standard deviation	0.547	0.339	0.448	0.214	0.619	0.294
Coefficient of variation	1.491	1.004	1.076	0.792	1.199	0.976
Skewness	3.122	1.761	3.194	1.614	2.806	2.076

Table 3.6: Summary statistics, annual catch rates for dhufish (total catch 5 x5nm/total effort 5 x 5nm) in the south of the West Coast bioregion.

Dhufish - south	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Count	165	154	153	130	94	105
Minimum	0	0	0	0	0	0
Maximum	2.25	2.0	1.0	1.0	2.0	1.6
Mean	0.31	0.275	0.249	0.238	0.3	0.216
Standard deviation	0.276	0.313	0.201	0.213	0.332	0.233
Coefficient of variation	0.889	1.137	0.809	0.893	1.109	1.081
Skewness	2.57	2.374	1.037	1.517	2.864	2.904

Table 3.7: Summary Statistics, annual catch rates for baldchin groper (total catch 5 x5nm/total effort 5 x 5nm) in the north of the West Coast bioregion.

Baldchin groper - north	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Count	96	88	90	95	95	89
Minimum	0	0	0.019	0	0	0
Maximum	3.25	2.1	1.215	1.369	2.667	2.834
Mean	0.398	0.303	0.288	0.368	0.372	0.296
Standard deviation	0.461	0.32	0.213	0.288	0.362	0.378
Coefficient of variation	1.159	1.055	0.74	0.783	0.975	1.277
Skewness	3.65	3.128	1.562	1.294	3.055	3.869

3.3.2 TJØSTHEIM'S INDEX A

Tjøstheim's index A of spatial association for catch rates (Figure 3.3) shows that the spatial association between years was weakest for dhufish, but strongest for baldchin groper and pink snapper. The values of Tjøstheim's index A for pink snapper and baldchin groper indicate positive spatial association across all pairs of consecutive years with the quotient statistically significant at the 5% confidence level (Table 3.9). In contrast for the overall catch and dhufish there is no indication of the presence of spatial association except for years 2006/07 and 2007/08 where the value of Tjøstheim's index A for dhufish is statistically significant.

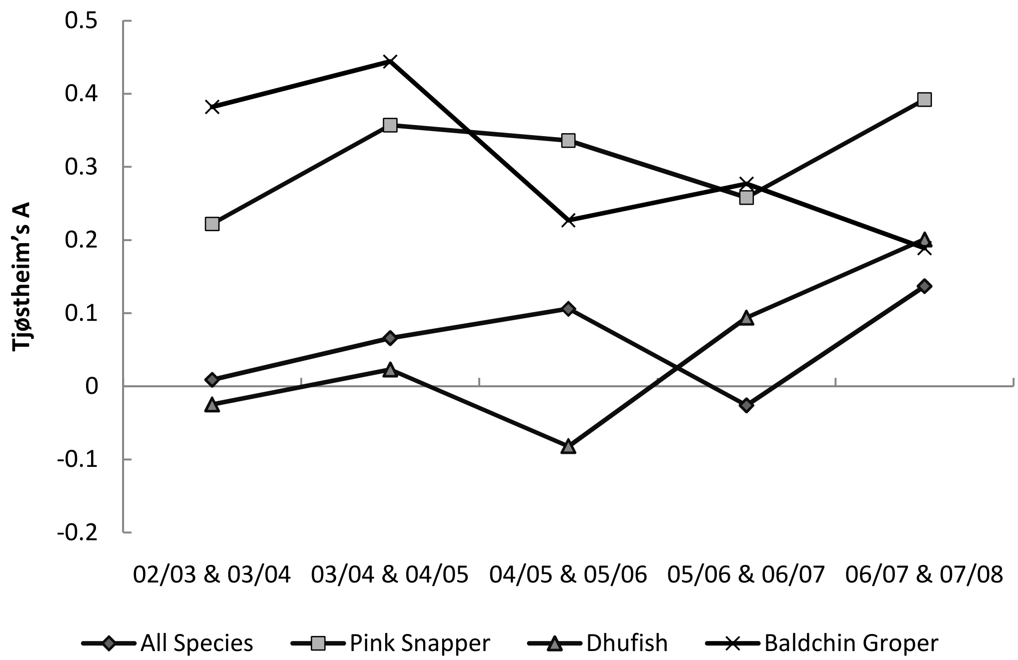

Figure 3.3: Tjøstheim's index A of spatial association for the overall catch rates on the west coast bioregion and pink snapper, dhufish and baldchin groper between consecutive years 2002/03 – 2007/08.

Table 3.8: Spatial correlations of West Coast catch rates (all species) between adjoining years.

Year	Tjøstheim's index A	quotient	Spearman (r)	Significance
2002/03 & 2003/04	0.009	1.572	0.540	No
2003/04 & 2004/05	0.066	1.013	0.627	No
2004/05 & 2005/06	0.106	1.583	0.528	No
2005/06 & 2006/07	-0.026	-0.376	0.515	No
2006/07 & 2007/08	0.137	1.949	0.575	No

Even though there was no statistically significant spatial association, there was a weak positive correlation, indicated by Spearman (r) between the values at common locations for consecutive years for all species. This was strongest for baldchin groper, for which Spearman (r) results further provided support for the observation that there was good similarity for locations in subsequent years.

Table 3.9: Spatial correlations of pink snapper catch rates between adjoining years.

Year	Tjøstheim's index A	quotient	Spearman (r)	Significance
2002/03 & 2003/04	0.222	3.219	0.502	Yes
2003/04 & 2004/05	0.357	4.963	0.489	Yes
2004/05 & 2005/06	0.336	4.598	0.558	Yes
2005/06 & 2006/07	0.258	3.263	0.590	Yes
2006/07 & 2007/08	0.392	5.137	0.542	Yes

Table 3.10: Spatial correlations of dhufish catch rates between adjoining years.

Year	Tjøstheim's index A	quotient	Spearman (r)	Significance
2002/03 & 2003/04	-0.025	-0.472	0.464	No
2003/04 & 2004/05	0.023	0.316	0.362	No
2004/05 & 2005/06	-0.082	-1.104	0.436	No
2005/06 & 2006/07	0.094	1.168	0.400	No
2006/07 & 2007/08	0.201	2.575	0.457	Yes

Table 3.11: Spatial correlations of baldchin groper catch rates between adjoining years.

Year	Tjøstheim's index A	quotient	Spearman (r)	Significance
2002/03 & 2003/04	0.382	4.105	0.703	Yes
2003/04 & 2004/05	0.444	4.448	0.698	Yes
2004/05 & 2005/06	0.227	2.343	0.677	Yes
2005/06 & 2006/07	0.277	2.629	0.754	Yes
2006/07 & 2007/08	0.189	1.979	0.404	Yes

3.3.3 VARIOGRAPHY

The semivariograms maps showed no strong evidence of anisotropy, thus isotropic models were fitted to the experimental semivariograms for the catch rates. Irrespective of the specific catch rate data set a nugget structure was required in the fit while the actual spatial structures differed from data set to data set. Catch rates for all species in the West Coast bioregion had a combination of a nugget structure and at most two spherical structures. The ranges of the models varied from 21nm in 2005/06 to 220nm in 2003/04. The spatial structure of catch rates for all species were long-ranged, except in 2005/06 and 2006/07, when they each had short-range variability in comparison to the other years and showed the greatest amount of variation in their spatial structure over a shorter distance (Figure 3.4 and Table 3.12). The semivariograms shown in the results have the same scales set for the semi variance so comparisons can be made over the study period, additional semivariograms with annualised scales are in the Appendix F for reference. The nugget to the total sill (relative nugget) percentage contribution varied between 16% and 39%, with 2006/07 having the highest micro-scale variability (Figure 3.7).

Table 3.12: Semivariogram model parameters, West Coast bioregion.

West Coast	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Nugget	1.2	1.0	1.03	0.8	1.88	0.63
$Structure_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
$Sill_1$	0.5	2.5	0.6	1.6	0.95	0.23
$Range_1$	20	220	32.6	21	89	42.8
$Structure_2$	Spherical		Spherical			Spherical
$Sill_2$	2.0		0.68			2.05
$Range_2$	184		170			215

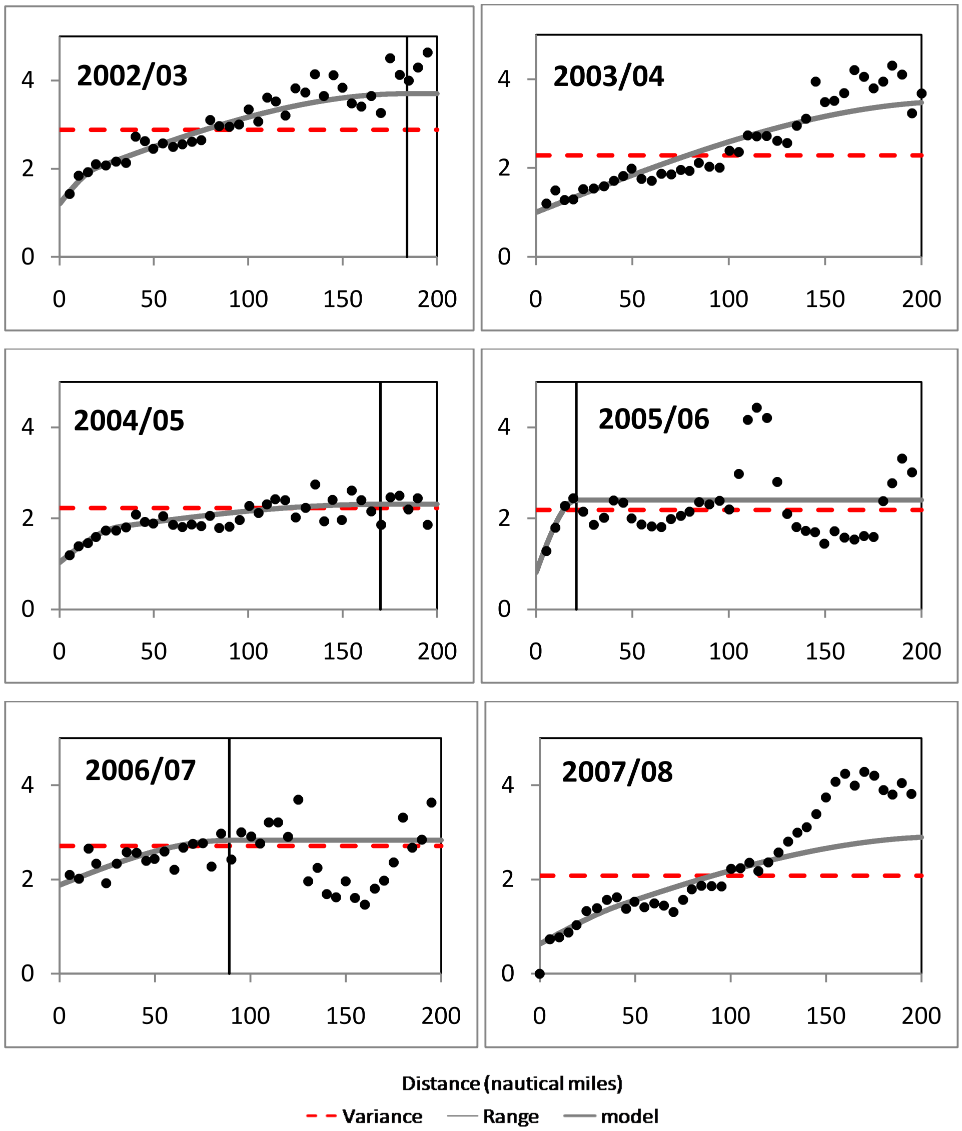

Figure 3.4: Semivariograms and models for the West Coast bioregion between 2002/03 and 2007/08.

For catch rates for all species in the northern extent of the West Coast bioregion the experimental semivariograms were fitted with models consisting of a nugget structure and a single spherical structure for all years. The contribution of the nugget to the total sill or the relative nugget, varied between 34% and 63%, with 2006/07 having the highest micro-scale variability (Figure 3.7). The ranges varied from 33nm in 2007/08 to 77nm in 2005/06 (Table 3.13 and Figure 3.5). In all cases the total sill was greater than the sample variance.

Table 3.13: Semivariogram model parameters, for catches in the north of the West Coast bioregion.

West Coast -north	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Nugget	1.5	1.8	1.05	0.87	1.0	0.5
$Structure_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
$Sill_1$	1.9	1.3	1.5	0.52	1.4	1.8
$Range_1$	58	60	61.5	77	50	33

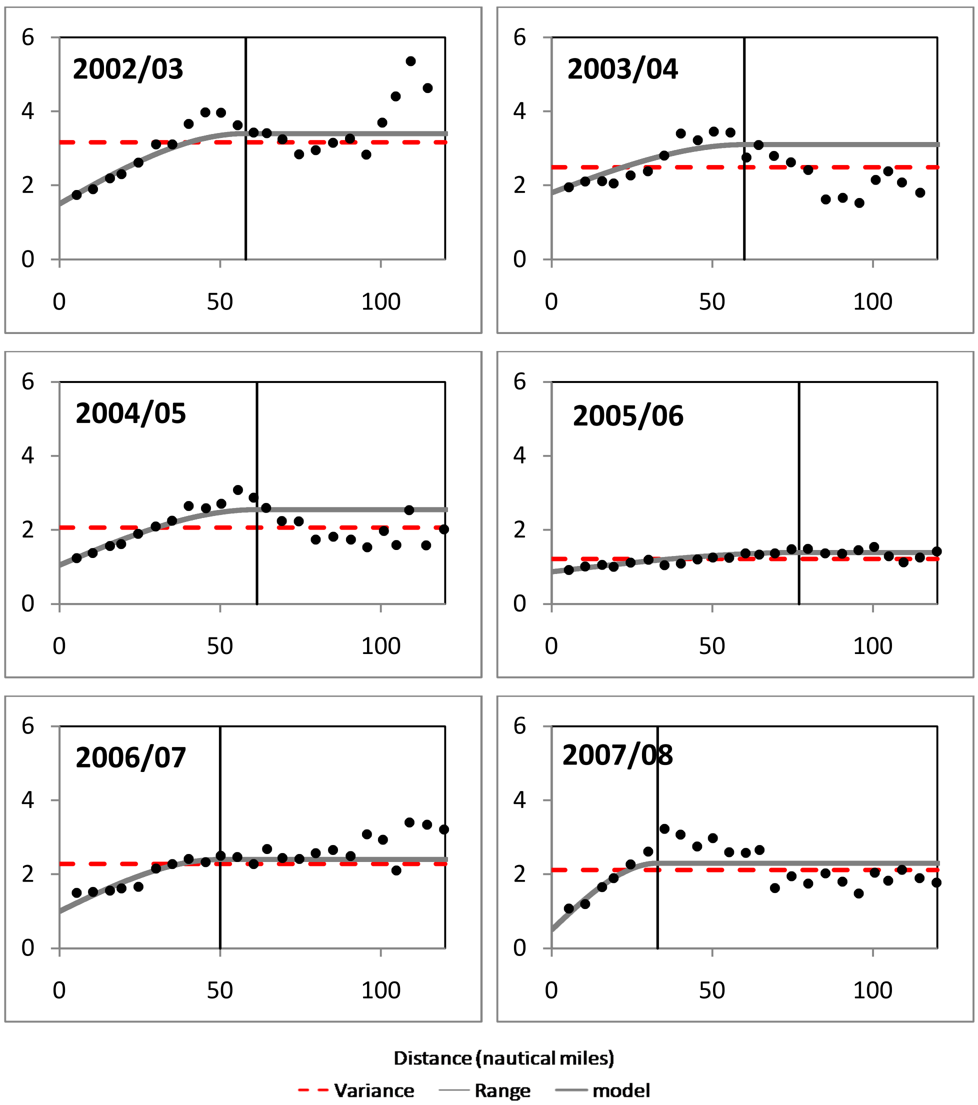

Figure 3.5: Semivariograms and models for the West Coast (north) bioregion between 2002/03 and 2007/08.

For the southern part of the West Coast bioregion the experimental semivariograms were fitted with models consisting of a nugget structure and a single spherical structure for all years. The contribution of the nugget to the total sill varied between 38% and 87%, with

2006/07 having the highest micro-scale variability (Figure 3.7). The ranges for the spherical components ranged from a low of 20.4nm in 2006/07 to 104nm in 2002/03 (Table 3.14 and Figure 3.6). For catch rates of all species on the West Coast bioregion the nugget to total sill ratio had similar behaviour in the north and south extent as well as the whole bioregion (Figure 3.7), in all cases the highest micro-scale variability was in 2006/07. Despite this, the range still differed between the north and south, in the north the range increased over the first five years of the study period, which was followed by a sudden decline in 2007/08. Whilst in the south the range for catch rates of all species decreased through the first five years of the study period, which was followed by a sudden increase in 2007/08. The overall pattern seems to be more strongly influenced by the south than the north.

Table 3.14: Semivariogram model parameters, for catch rates in the south of the West Coast bioregion.

West Coast -south	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Nugget	0.99	0.68	1.04	1.54	2.7	0.37
$Structure_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
$Sill_1$	1.6	0.89	0.6	1.7	0.39	0.26
$Range_1$	104	72.5	31	45.5	20.4	91.9

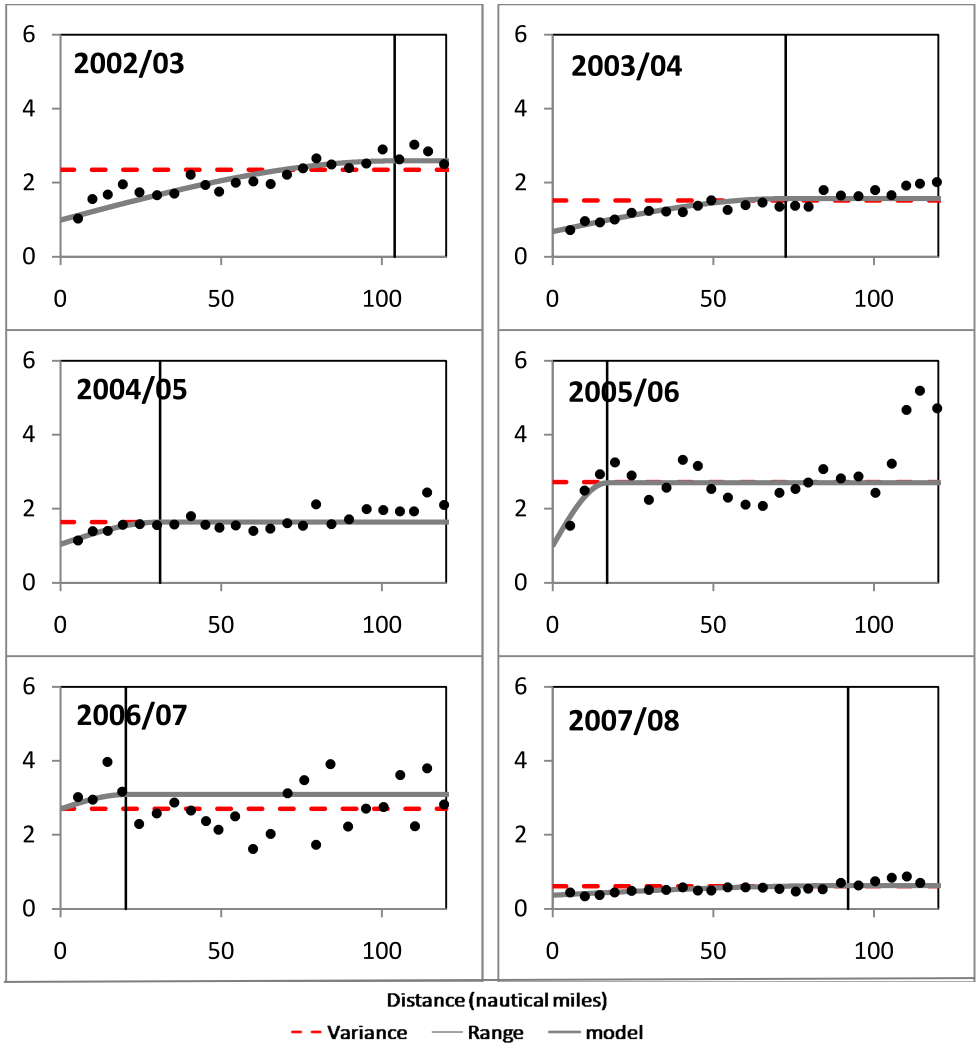

Figure 3.6: Semivariograms and models for the West Coast (south) bioregion between 2002/03 and 2007/08.

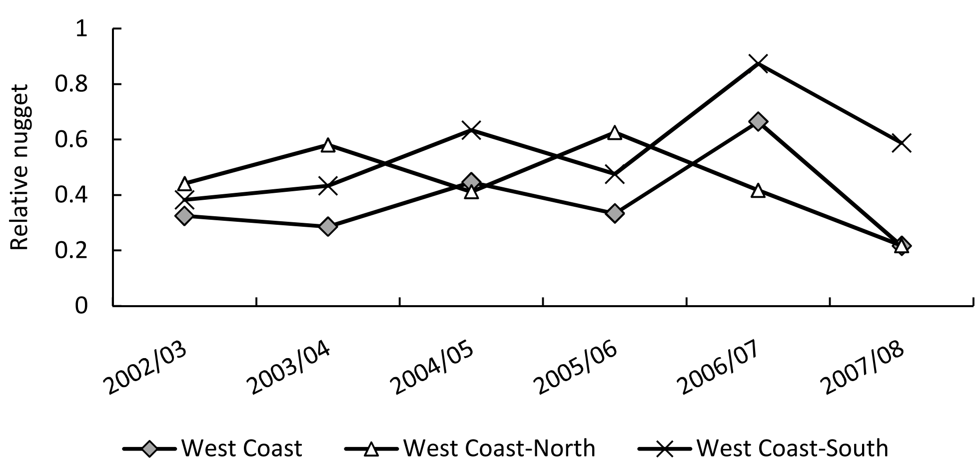

Figure 3.7: Relative nugget (nugget to total sill ratio), for the West Coast, West Coast - north and West Coast - south.

For pink snapper catch rates in the northern extent of the West Coast bioregion the experimental semivariograms were fitted with models consisting of a nugget structure and a single spherical structure (Figure 3.8). The contribution of the nugget to the total sill varied between 58% and 17%, with 2005/06 having the highest micro-scale variability (Figure 3.10). The ranges for the spherical components fluctuate from 36nm in 2004/05 to 61nm in 2007/08 (Table 3.15 and Figures 3.8 and 3.11).

Table 3.15: Semivariogram model parameters, for the pink snapper catches in the north of the West Coast bioregion.

Pink snapper - north	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
Nugget	0.07	0.2	0.3	0.11	0.36	0.19
$Structure_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
$Sill_1$	1.0	0.33	0.23	0.08	0.77	0.55
$Range_1$	50	62	36	37	61.3	37

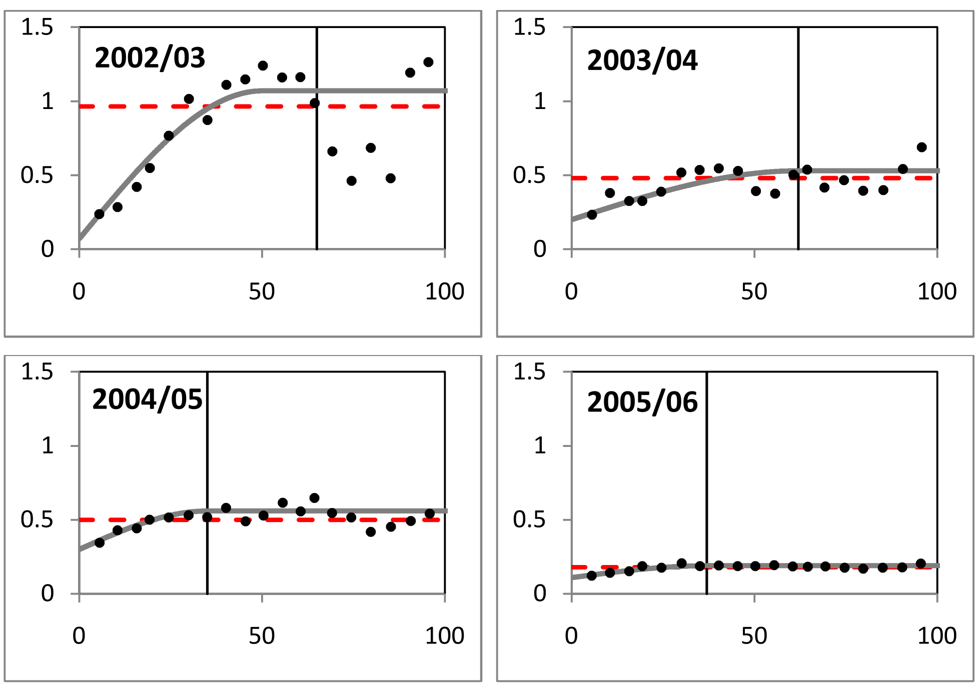

Figure 3.8: Semivariograms and models for the pink snapper (north) West Coast bioregion between 2002/03 and 2007/08.

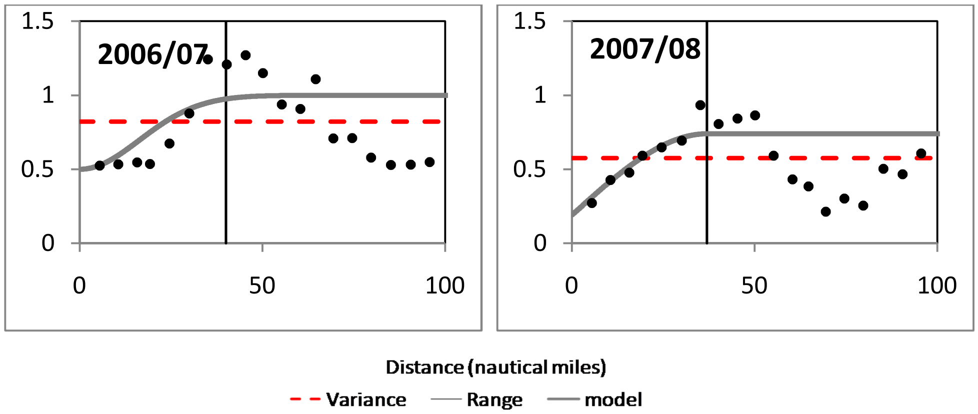

Figure 3.8 continued: Semivariograms and models for the pink snapper (north) West Coast bioregion between 2002/03 and 2007/08.

For pink snapper catch rates in the southern extent of the West Coast bioregion the experimental semivariograms were fitted with models consisting of a nugget structure and a single spherical structure (Figure 3.9). The contribution of the nugget to the total sill varied between 34% and 64%, with 2004/05 having the highest micro-scale variability (Figures 3.10 and Appendix F4). The ranges for the spherical components fluctuated from 20nm in 2004/05 to 39nm in 2003/04, which is small in comparison to the range in the north (Table 3.16 and Figure 3.11).

Table 3.16: Semivariogram model parameters, for the Pink Snapper catches in the south of the West Coast bioregion.

Pink snapper - south	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Nugget	0.10	0.038	0.08	0.025	0.19	0.04
Structure$_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
Sill$_1$	0.19	0.075	0.05	0.02	0.2	0.06
Range$_1$	30	39	20	17	29	29

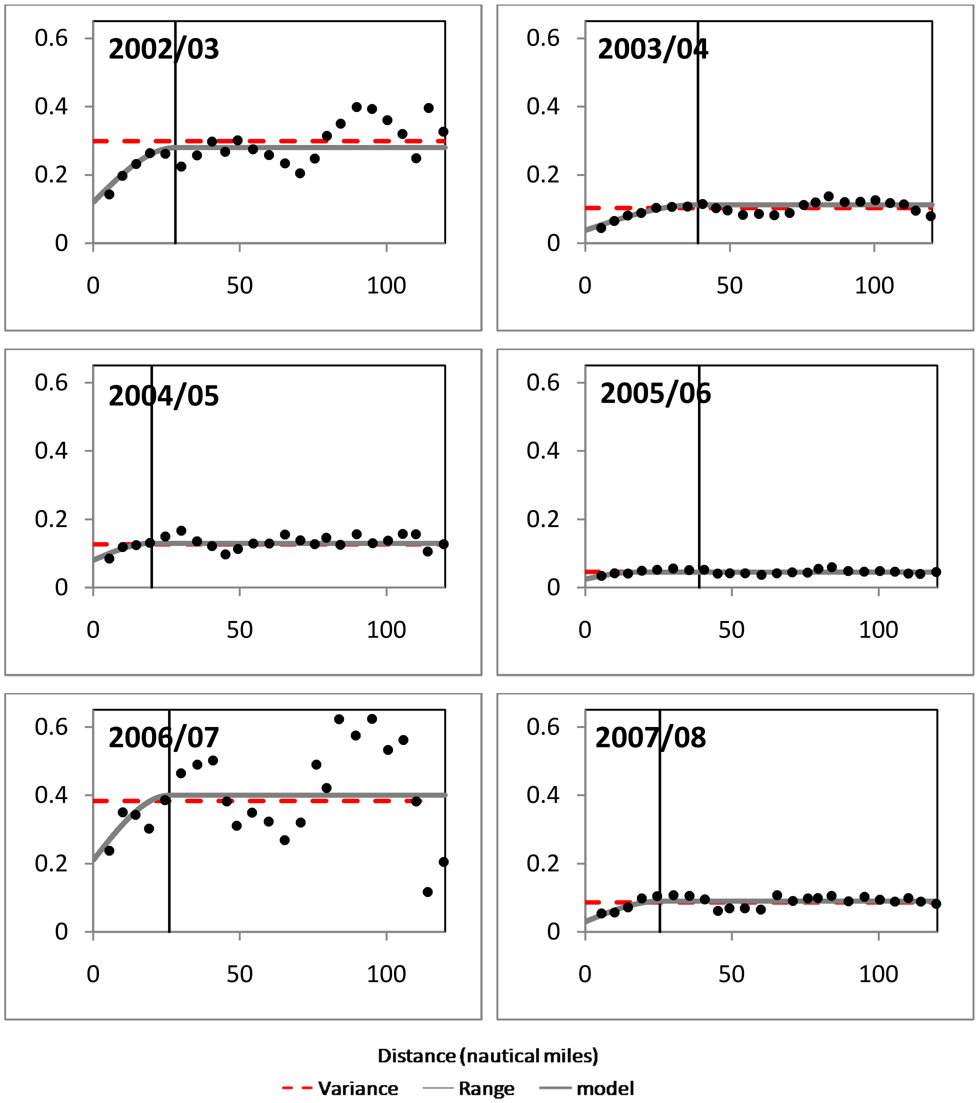

Figure 3.9: Semivariograms and models for the pink snapper (south) West Coast bioregion between 2002/03 and 2007/08.

The overall patterns of the model ranges were not too dissimilar between pink snapper in the north and south (Figure 3.11). In both extents, the shortest range of variability occurred in 2004/05 and 2005/06 with the longest range occurring in 2003/04 (Figure 3.11). The model ranges across all years were higher in the north, indicating a better spatial correlation over a larger distance. The nugget to total sill ratio for pink snapper in both extents were also similar, with the highest micro-scale variability one year apart.

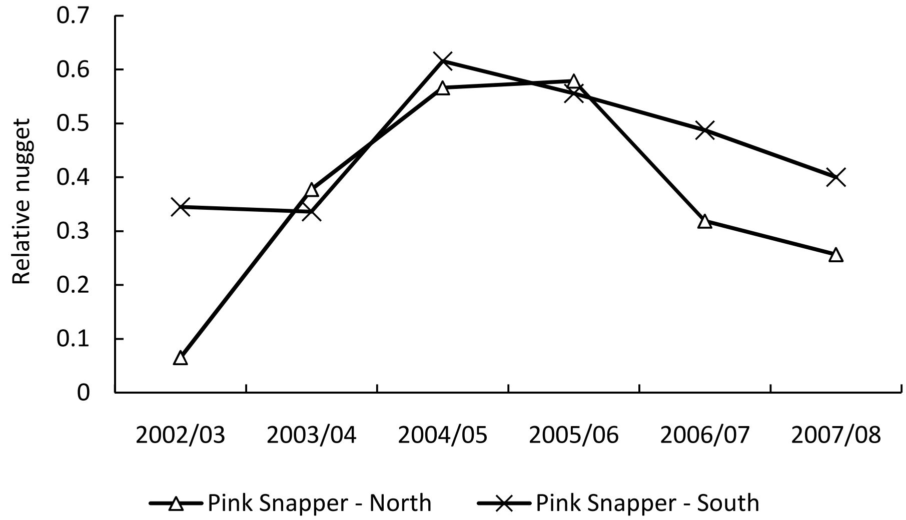

Figure 3.10: Relative nugget (nugget to total sill ratio), for pink snapper in the north and pink snapper in the south of the West Coast bioregion.

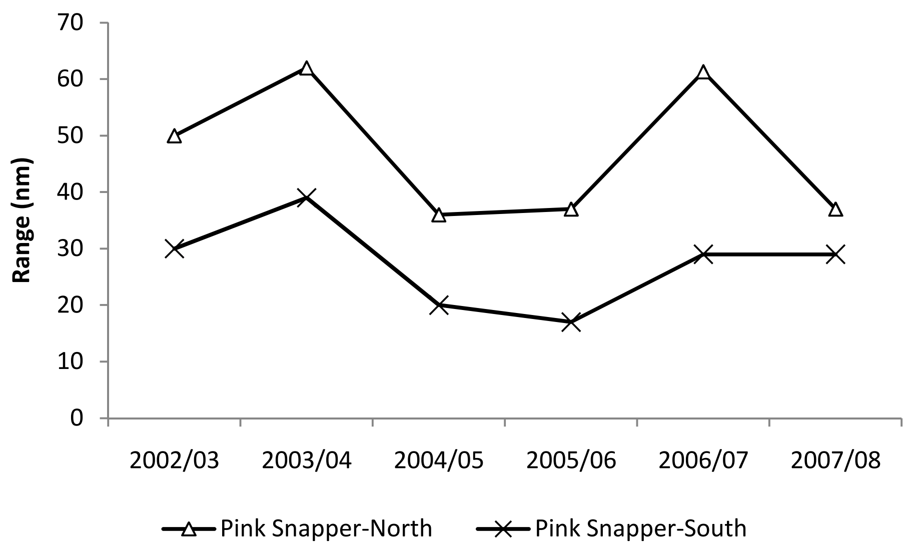

Figure 3.11: Ranges (nm) for pink snapper in the north and pink snapper in the south of the West Coast bioregion.

The experimental semivariograms for dhufish in the south of the West Coast bioregion were fitted with models consisting of a nugget structure and a single or double spherical structure (Table 3.17, Figure 3.12 and Appendix F5). The contribution of the nugget to the total sill varied between 24% and 70%, with 2004/05 having the highest micro-scale variability (Figure 3.14). The ranges for the spherical components fluctuated from 122nm in 2003/04 to 44nm in 2004/05.

Table 3.17: Semivariogram model parameters, for the dhufish catches in the south of the West Coast bioregion.

Dhufish - south	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Nugget	0.041	0.046	0.03	0.02	0.026	0.02
$Structure_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
$Sill_1$	0.05	0.083	0.013	0.011	0.034	0.036
$Range_1$	89	122	44	19	14	33
$Structure_2$				Spherical	Spherical	
$Sill_2$				0.015	0.05	
$Range_2$				61	58	

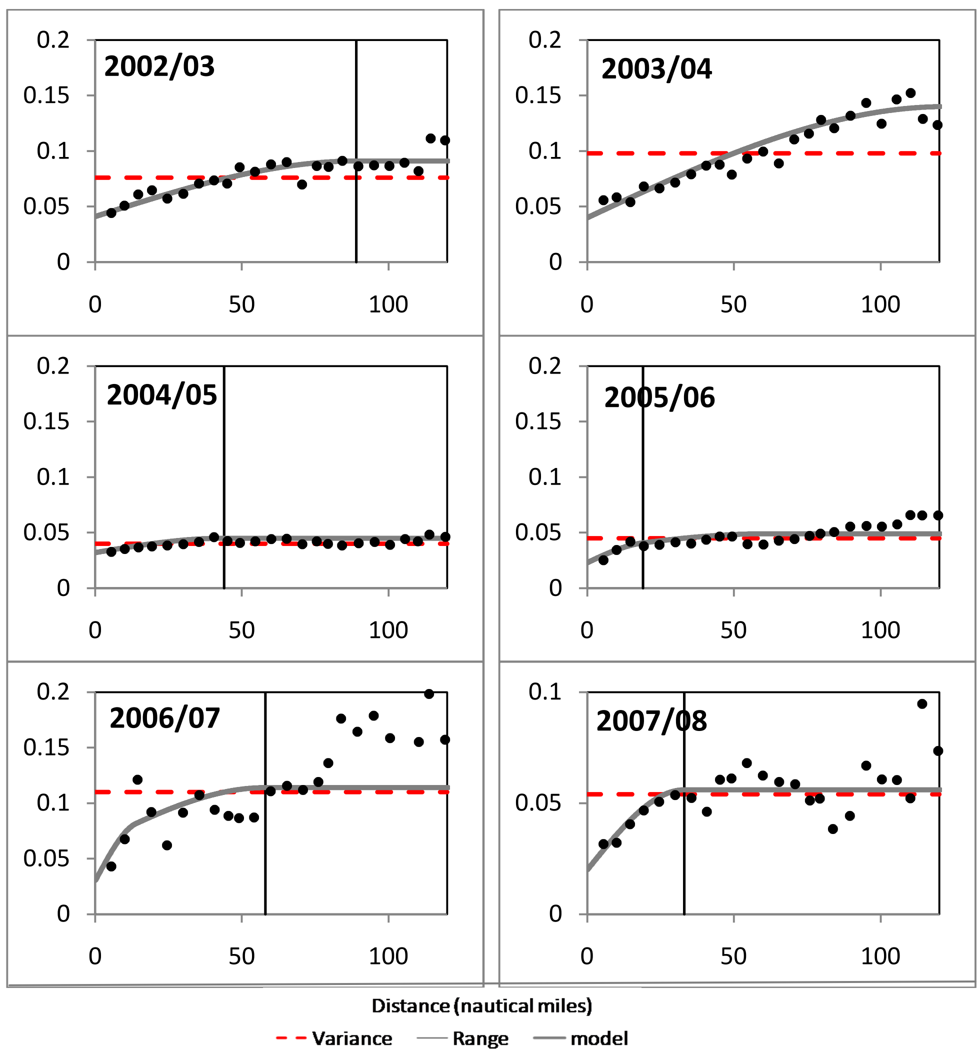

Figure 3.12: Semivariograms and models for the dhufish (south) West Coast bioregion between 2002/03 and 2007/08.

The experimental semivariograms for baldchin groper in the northern extent of the West Coast bioregion were fitted with models consisting of a nugget structure and a single spherical structure (Table 3.18, Figure 3.13 and Appendix F6). The contribution of the nugget to the total sill varied between 22% and 76%, with 2002/03 having the highest micro-scale variability (Figure 3.14). The ranges for the spherical components had an increasing trend over the study period, in the last three years the range is almost three times that in the first two years. However in the last three years the variability was much larger and the overall experimental semivariogram of baldchin groper catch rates were noisier.

Table 3.18: Semivariogram model parameters, for the baldchin groper catches in the north of the West Coast bioregion.

Baldchin groper - north	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08
Nugget	0.17	0.068	0.028	0.041	0.09	0.034
Structure$_1$	Spherical	Spherical	Spherical	Spherical	Spherical	Spherical
Sill$_1$	0.055	0.038	0.024	0.041	0.046	0.12
Range$_1$	15	14	20	44	47	44

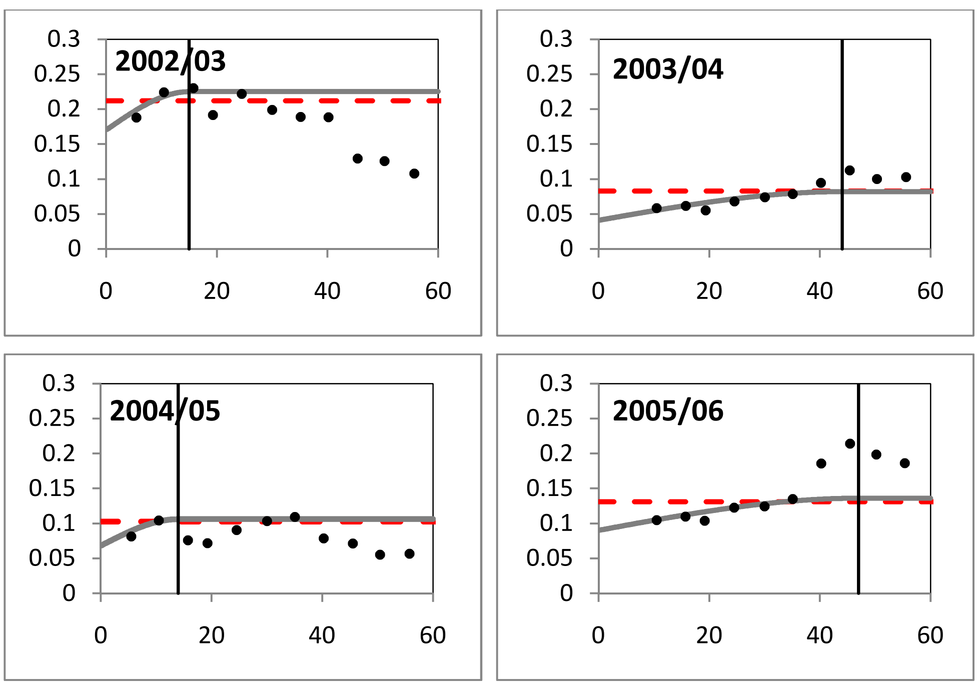

Figure 3.13: Semivariograms and models for the baldchin groper (north) West Coast bioregion between 2002/03 and 2007/08.

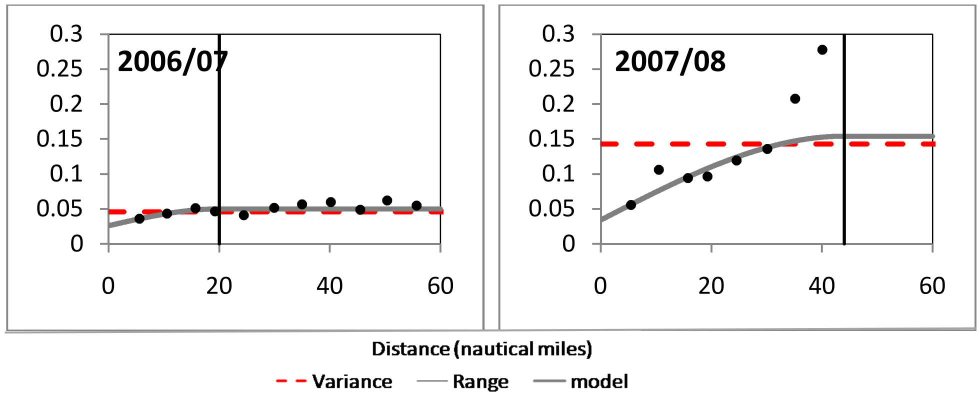

Figure 3.13 continued: Semivariograms and models for the baldchin groper (north) West Coast bioregion between 2002/03 and 2007/08.

Figure 3.14: Relative nugget (nugget to total sill ratio), for baldchin groper in the north and dhufish in the south of the West Coast bioregion.

3.3.4 KRIGING

The spatial maps derived by kriging the catch rate estimates for all species combined on the West Coast bioregion showed that overall the northern extent of the bioregion had consistently higher catch rates (greater than 2.0) compared to the south throughout the study period. In comparison, the southern extent of the West Coast bioregion indicated a decrease in catch rate between 2002/03 and 2007/08 with the majority ranging between 0.952 and 1.980, particularly around the Perth and Bunbury areas (Figure 3.15), with limited hot-spots present. This was particularly notable in 2007/08, when the spatial map had low catch rates (less than 1.5) for all of the southern extent of the West Coast bioregion (Figure 3.15).

On closer examination of the northern extent of the West Coast bioregion, the highest catch rate for all species was around the Abrolhos Island. In 2005/06 there was spatial evidence of a decline in area of catch rates greater than 4.174 compared to other years (Figure 3.16). The spatial maps for the northern extent of the bioregion had a greater proportion of hot spots (catch rates of 8.431) on the west side (between 6800 and 6850nm longitude) of the Abrolhos Islands in each year, again this was limited in 2005/06.

The overall spatial area of the fishing grounds in the southern extent of the West Coast bioregion contracted between 2002/03 and 2007/08, and the catch rates for all species were particularly low (less than1.5) throughout the whole region in 2007/08, with the exception of small hot spot cluster in the north on the edge of the extent (Figure 3.17). In the first 3 years there were areas of catch rate hot spots (7.584) around Perth and Bunbury, however by 2005/06 to 2007/08 they were not present.

The spatial maps derived from kriging pink snapper catch rates in the northern extent had hot spots within the Abrolhos Islands, with the exception of 2005/06 (between -1750nm and -1825nm latitude, Figure 3.18). The overall spatial area of the fishing grounds in the north was variable across all years, with low catch rates (less than 0.587) near the coastline, inshore compared to offshore regions. In the southern extent, the kriging estimates for pink snapper highlighted a greater proportion of areas with low catch rates (less than 0.262) particularly in 2005/06 and 2007/08 (Figure 3.19). Pink snapper catch rates had variable hot spots across the study period with no particular pattern evident. The majority of high catch rates (greater than 0.695) were located further offshore and were on the west side of the study area (<6925nm longitude). The overall spatial area of the fishing grounds for pink snapper in the southern extent of the West coast bioregion reduced in area between 2002/03 and 2007/08, as a result of a decrease in the number of block locations where fishing activity was recorded for pink snapper (Table 3.5).

The southern extent of the West Coast bioregion is the preferred habitat for dhufish, so kriging estimates were restricted this extent only. In 2002/03 and 2003/04 there were large hot spots areas of catch rate estimates (1.017) (Figure 3.20). Whilst in 2004/05 there were no hot spots present. In contrast, between 2005/06 and 2007/08 only small hot spots were present but scattered around the extent, with the last two years highlighting similar hot spot locations. This was also indicated by Tjøstheim's index A for dhufish which showed that there was no spatial association between consecutive years until 2006/07, when there was spatial association present.

In contrast to dhufish, kriging catch rate estimates for baldchin groper were restricted to the northern extent of the West Coast bioregion, as it is their preferred habitat. For baldchin groper hot spots catch rates were (1.484) present in all years with the exception of 2004/05 (Figure 3.21), with the majority of hot spots located on the west extent of the Abrolhos Islands. The overall spatial extent of the fishing grounds was relatively constant throughout the study period with no significant reduction or increase in area. Tjøstheim's index A also showed this as all years had spatial association and the quotient shows that all years were statistically different.

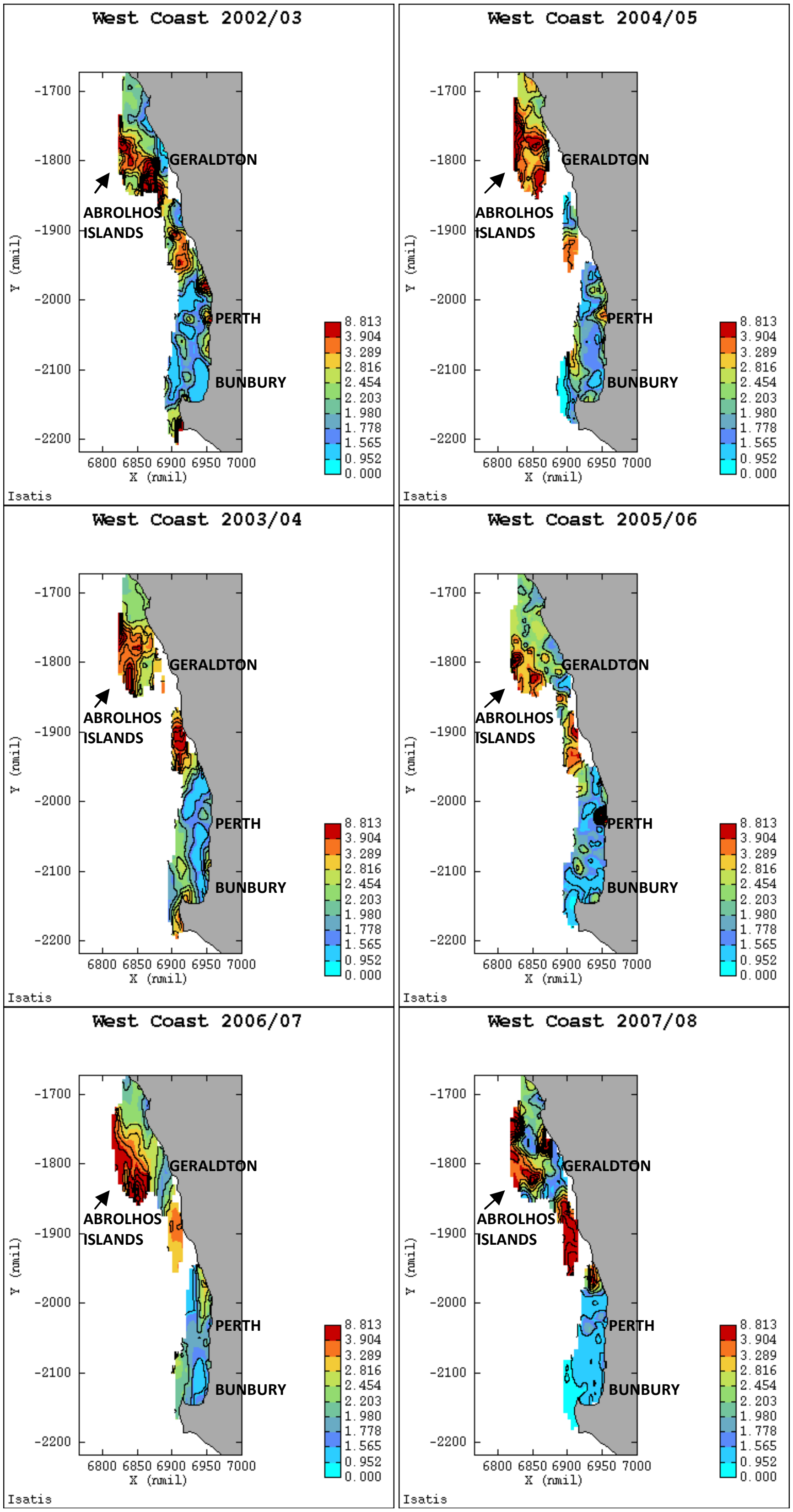

Figure 3.15: Spatial maps, West Coast charter catch rate estimates 2002/03 to 2007/08 (x- longitude, y-latitude) Isolines highlight areas of the same value.

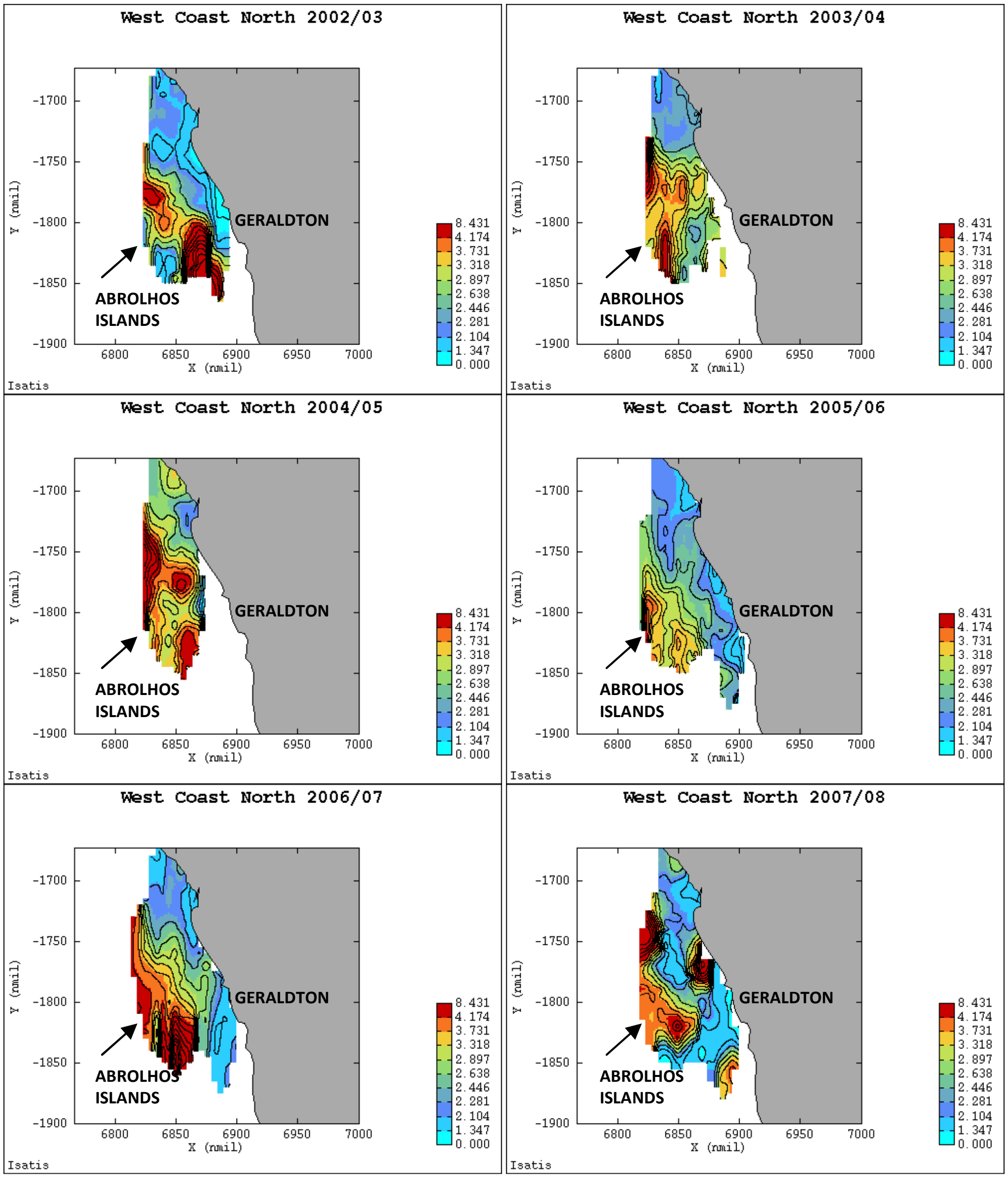

Figure 3.16: Spatial maps, West Coast (north) charter catch rate estimates 2002/03 to 2007/08 (x- longitude, y-latitude) Isolines highlight areas of the same value.

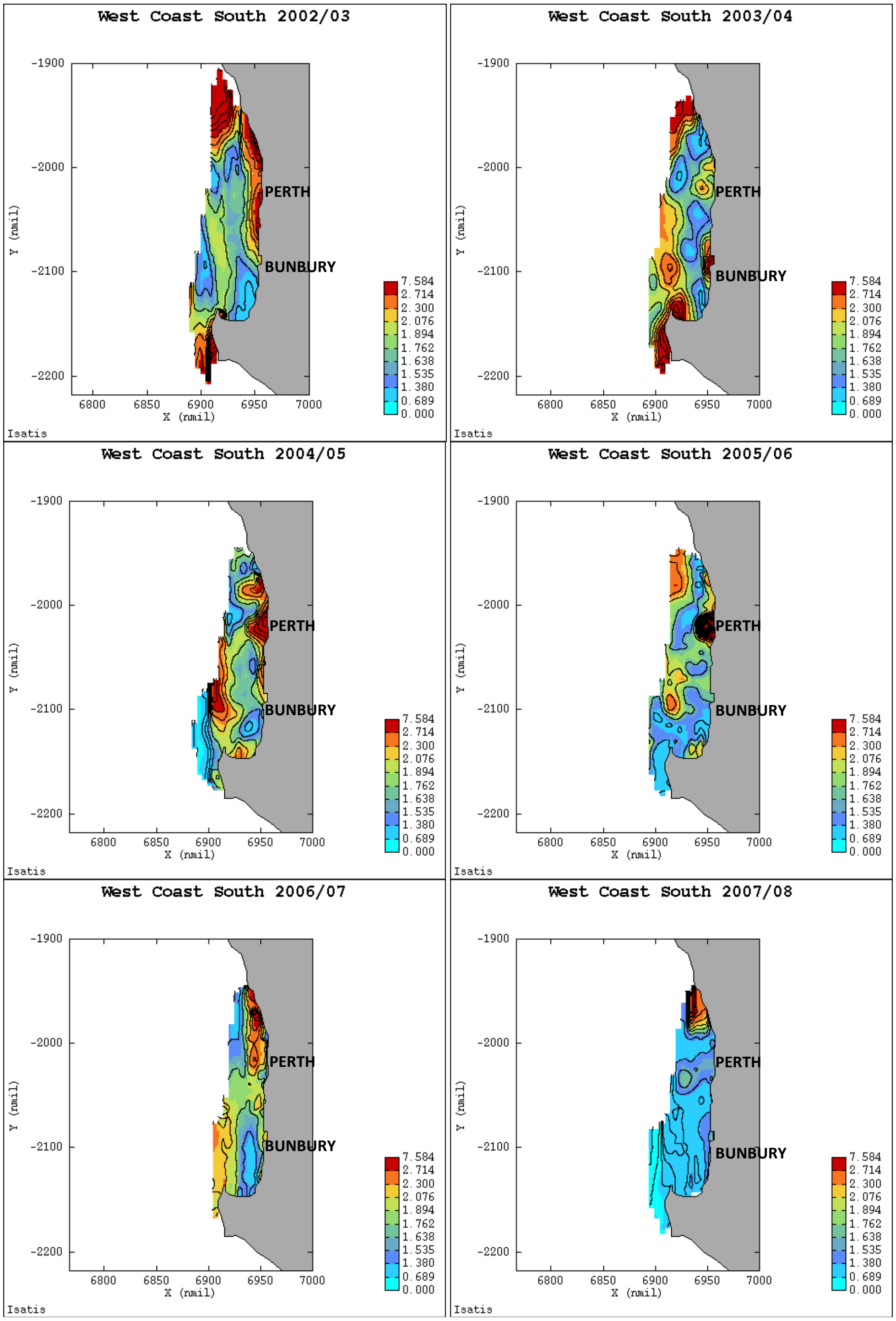

Figure 3.17: Spatial maps, West Coast (south) charter catch rate estimates 2002/03 to 2007/08 (x-longitude, y-latitude) Isolines highlight areas of the same value.

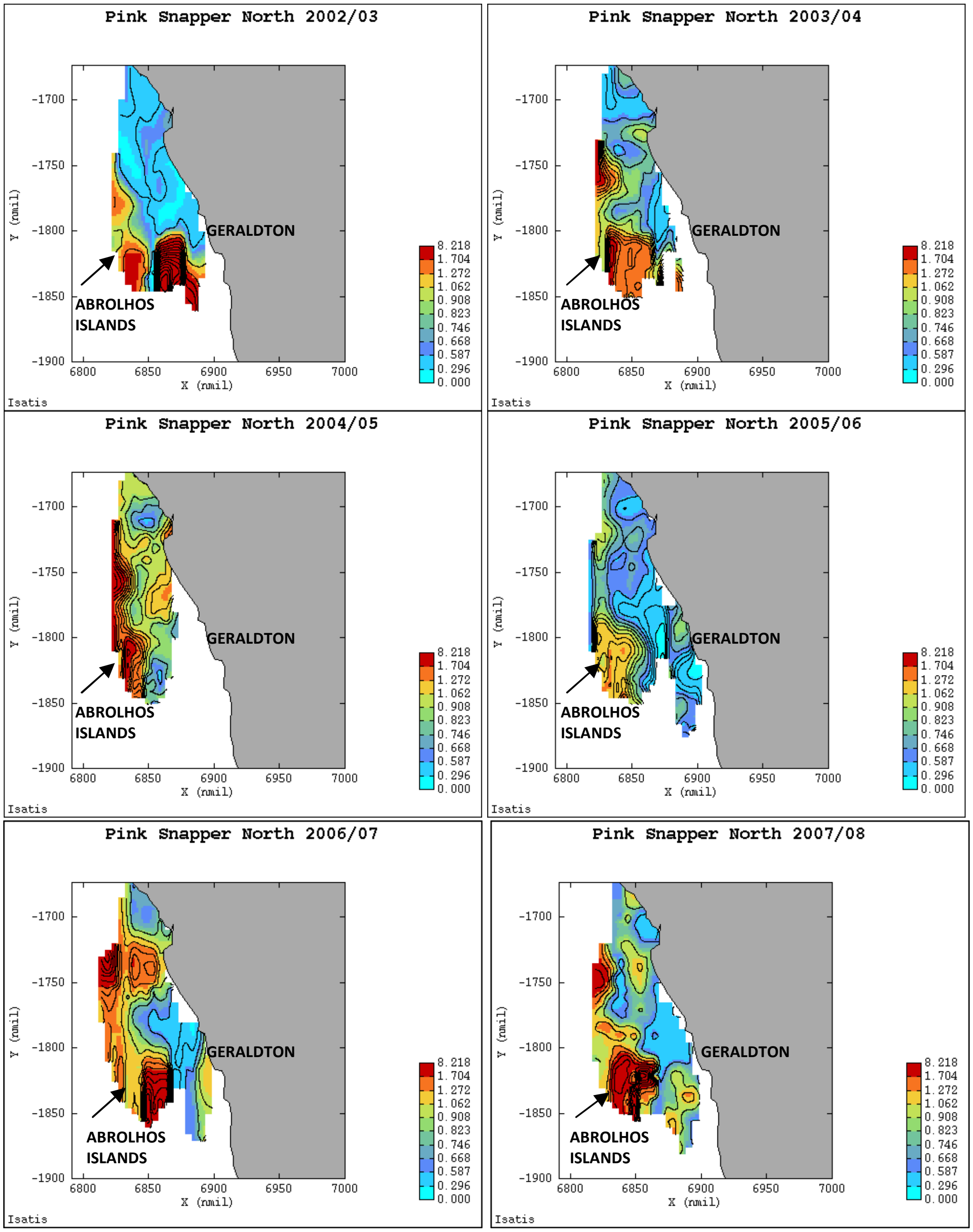

Figure 3.18: Spatial maps, pink snapper (north) catch rate estimates 2002/03 to 2007/08 (x- longitude, y-latitude) Isolines highlight areas of the same value.

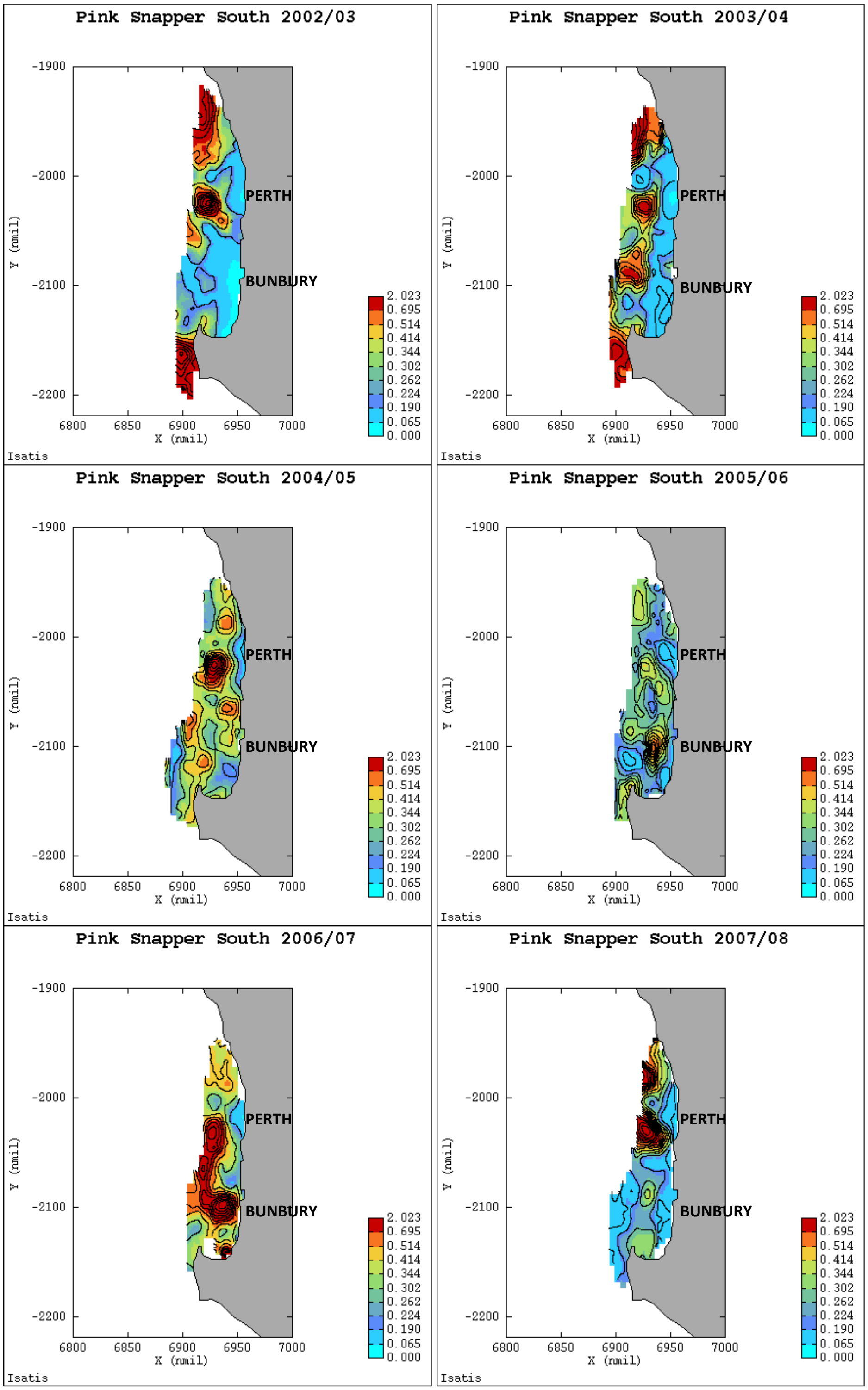

Figure 3.19: Spatial maps, pink snapper (south) catch rate estimates 2002/03 to 2007/08 (x- longitude, y-latitude) Isolines highlight areas of the same value.

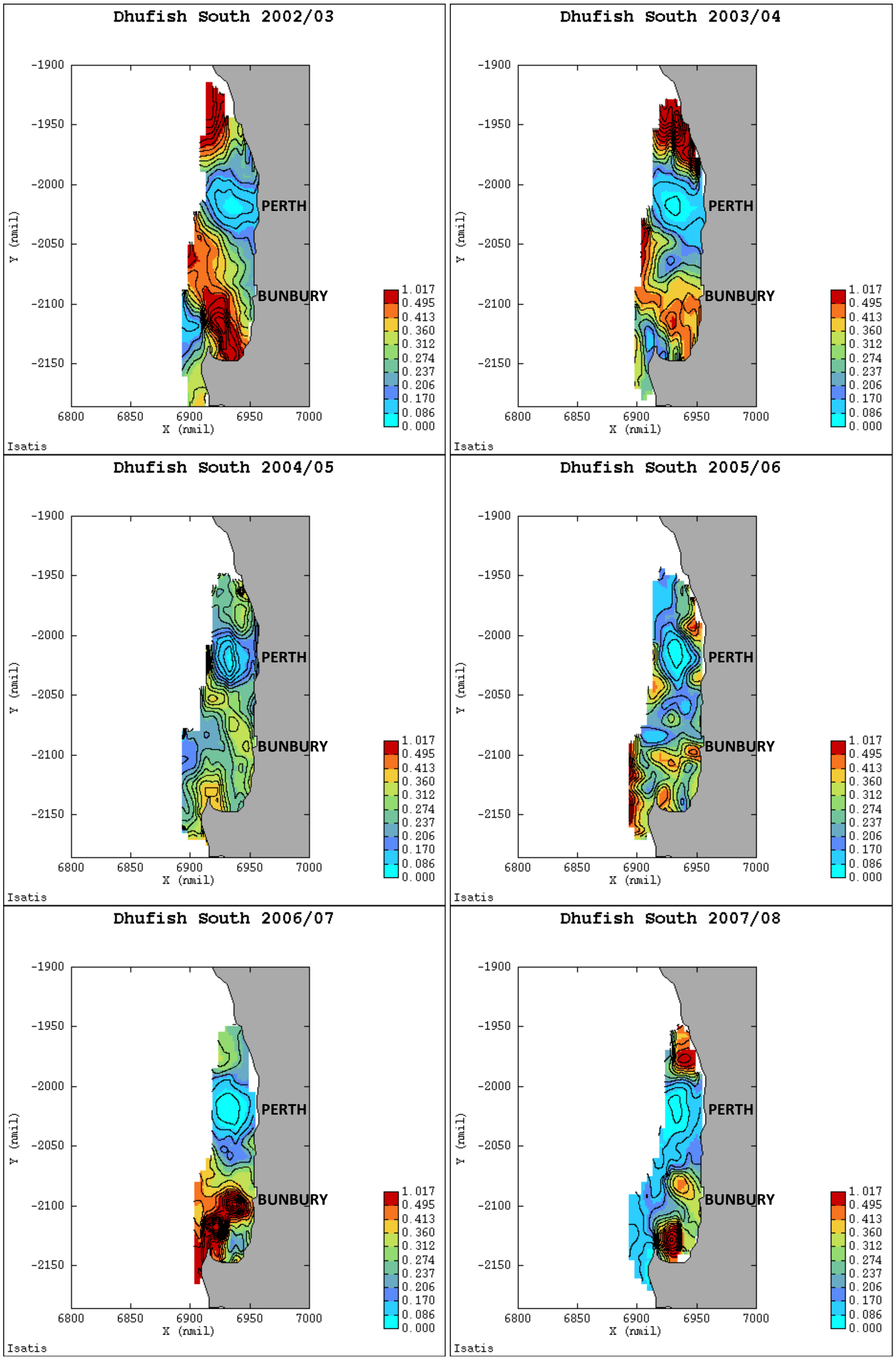

Figure 3.20: Spatial maps, dhufish (south) catch rate estimates 2002/03 to 2007/08 (x-longitude, y-latitude) Isolines highlight areas of the same value.

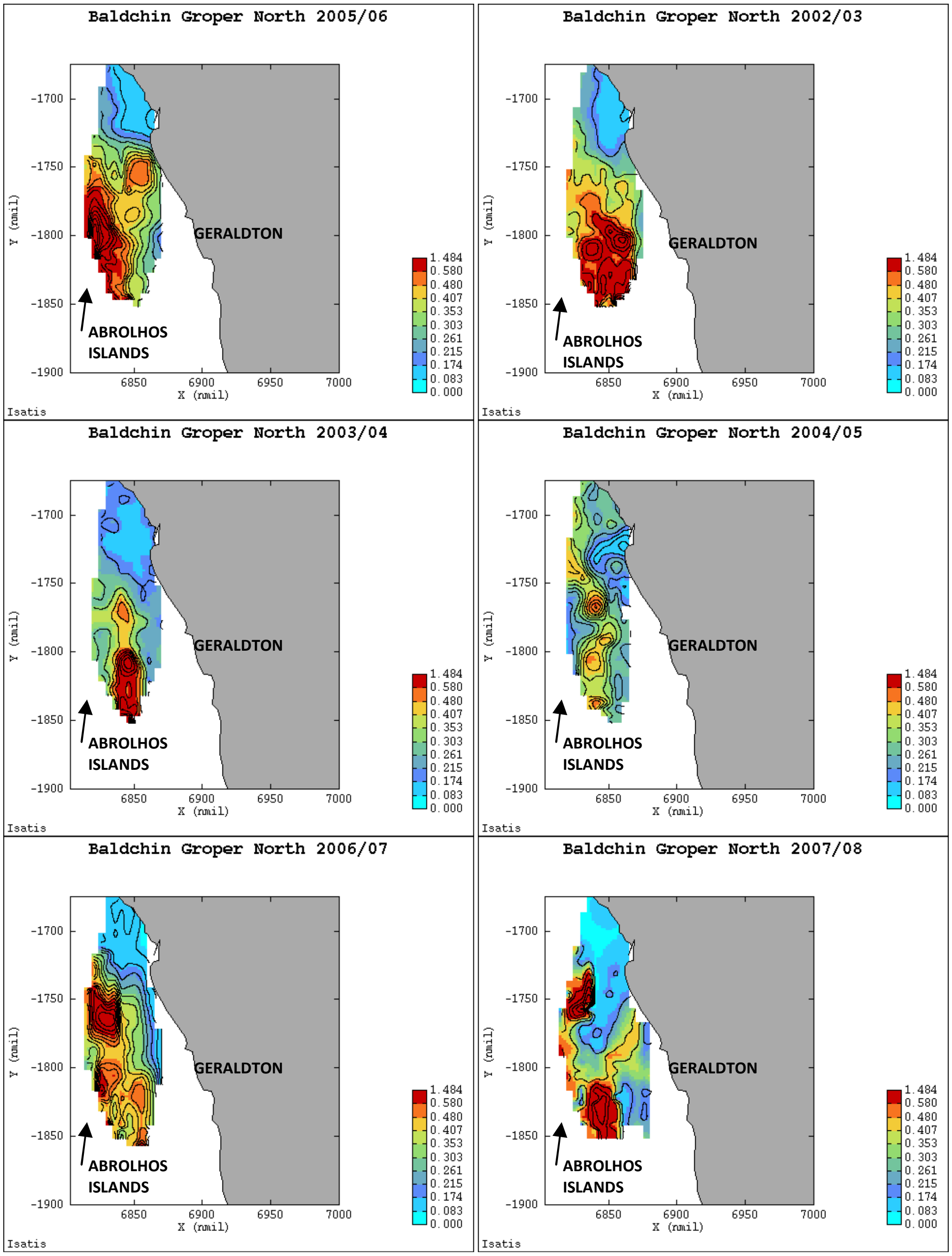

Figure 3.21: Spatial maps, baldchin groper catch rate estimates 2002/03 to 2007/08 (x- longitude, y-latitude) Isolines highlight areas of the same value.

3.4 DISCUSSION

For all three indicator species examined in this study, geostatistical analyses identified spatial patterns in catch rates of high and low density (patches) for the charter industry in the West Coast bioregion. The geostatistical approach also showed moderate changes in the spatial structure between 2002/03 and 2007/08. Ordinary kriging estimates showed that the majority of low catch rate values occurred near Bunbury, which was particularly evident in the catch rates for pink snapper. There was an increase in the ranges of semivariogram models for baldchin groper catch rates, whilst for dhufish and pink snapper there was variability in the ranges with no consistent increase or decrease. Geostatistical analysis also highlighted changes in local catch rate densities within the bioregion, independent of the species. Overall, the spatial structure of catch rates from the charter boat industry in the West Coast bioregion has undergone moderate spatial changes over the study period.

The change in spatial structure in the West coast bioregion for all species collectively was particularly evident in 2005/06 and 2006/07 when the range of continuity dropped from 220 nautical miles in 2003/04 to 21 nautical miles within two years. This change represents a greater amount of variation in the spatial structure of catch rates over a short distance. A comparison between the northern and southern extent of the bioregion indicated that the spatial structures for all species were consistent across all years in the north, but variable in the south. The relative nugget values (nugget to sill ratio) in both the north and south of the bioregion were similar, with both peaking in 2006/07. The nugget effect, combined with the short range, indicates that most of the spatial correlation was confined to distances shorter than the sampling interval, greater than 5 nautical miles, and in the absence of anisotropy (direction). This was also confirmed by the Tjøstheim’s index A which showed, that there was no spatial association between 2005/06 and 2006/07.

The spatial structure of pink snapper catch rates in the northern extent of the West Coast bioregion varied between years, with the variation occurring in clustered years. In contrast, in the southern extent, the spatial structure of pink snapper catch rates was relatively consistent across all years. However the range was considerably smaller than in the north, varying between only 17 nautical miles and 39 nautical miles. In both extents, the relative nugget had an increasing trend, before declining, with the northern extent peaking in 2005/06 and the southern extent peaking a year earlier in 2004/05. These two peaks coincide with the smallest ranges over the time period. Similar patterns occurred in catch rates for all species, with the only difference occurring in the timing of the increased relative nugget. In the southern extent of the bioregion with the number of block locations reported, catch rates of pink snapper decreased by almost 50%, however this remained stable in the northern extent. The decrease in the number of blocks, may account for some of the changes in the spatial structure. There is no clear evidence to suggest why there was a decrease in the number of block locations, however spatial distribution of species in data is heavily influenced by a fisherman's choice of fishing location (Kleisner *et al.,* 2010). Kriging results highlighted that pink snapper catch rate distributions have contracted in spatial extent and catch rates remained lower in the southern extent of the bioregion, particularly in 2005/06 and 2007/08, again possibly due to the decrease in the number of fishing block locations. Research conducted on pink snapper around Perth, revealed that distribution of the species varied according to the stage of its life cycle and ages and lengths tended to increase progressively as they moved offshore and further west (Wakefield *et al.*, unpublished 2010). Biases in the sampling from Wakefield study (2010), highlighted that charter vessels frequented these offshore areas on every observed trip using the same gear and targeting very similar habitats (i.e. high and low relief reef) (Wakefield *et al.*, unpublished 2010).

The spatial maps for pink snapper showed evidence of shifts in catches offshore, with no catches in the immediate areas off the west coast bioregion coastline by 2007/08. The low catch rates observed in the southern extent of the bioregion, particularly in the Bunbury area, reflect the distribution of the species, as opposed to a change in the relative abundance, as the area does not contain the preferred habitat for the species (Wakefield, personal communication, 2010). Overall, the spatial structure of pink snapper catch rates identified some changes, with the presence of greater variability between years, possibly as a result of charter operators identifying the preferred habitat where pink snapper reside.

There were also some spatial changes evident in dhufish catch rates in the southern extent of the West Coast bioregion, particularly in relation to the increasing trend in its relative nugget, which peaked in 2005/06, and the varying ranges between 2003/04 (122 nautical miles)and 2004/05 (44 nautical miles). This highlights an increase in the amount of short distance variation in the spatial structure. Unlike pink snapper, dhufish are endemic to Western Australia (Lenanton *et al.*, 2009) and, with increases in technology, there have been increases in their rate of exploitation leading to a decline in its abundance off Perth (Hesp *et al*., 2002). Kriging results support this, identifying the 43% decrease in the number of block locations in which this species was caught between 2002/03 to 2006/07. Also, of the three indicator species, dhufish had the lowest mean catch rate throughout the study period. More positively, there were signs of recovery or change in the spatial pattern in 2006/07 and 2007/08, with areas of high catch rates occurring again after being absent for two years prior. This also coincided with a change in the relative nugget during the same time. The suspected recovery was also supported by Tjøstheim's index A of spatial association, which was weakest for dhufish, showing no spatial association between consecutive years from 2002/03 and 2005/06 and low spatial association between consecutive years from 2005/06 and2007/08. However, since dhufish are lifetime residents of their particular geographical location and movement in both adults and juveniles is small (Wise *et al.*, 2007), a 43% decrease in the number of block locations in which this species was caught may be the result of charter operators having knowledge of the preferred habitat where dhufish reside, together with technology such as Geographical Positioning Systems (GPS) to mark these locations, as also observed for pink snapper.

The spatial structure of baldchin groper was more consistent than that of pink snapper or dhufish. There was an increase in the ranges of semivariogram models with the range of continuity increasing from 14 nautical miles in 2003/04 to 47 nautical miles in 2006/07, which indicates a smaller variation in the correlation over a greater distance. Tjøstheim's index A showed that all years were spatially associated and locations of high and low catch rates did not change substantially, with the exception of the last two years. In general, there was similarity in the spatial distribution of catch rates throughout the study period. The relative nugget decreased over the study period, with only a slight increase in 2006/07. The most notable change for baldchin groper was seen in the kriging results, with high catch rates shifting over the study period, from the southern extent of the Abrolhos Islands in earlier years to the western edge of the Islands and a drift further north in the later years. Like dhufish, baldchin groper are endemic to Western Australia, but are distributed more abundantly in the Abrolhos Islands. Their preferred habitat and spawning areas are near or in benthic reef habitats (Wise *et al.*, 2007). Limited studies have been done on the movement of this species, however, tagging studies revealed that, like dhufish, individual baldchin groper have restricted home ranges (Wise *et al.*, 2007). The major commercial fishery of the Abrolhos Islands is the Western rock lobster fishery, however, the commercial and recreational (including charter) sectors now target a suite of species including pink snapper, baldchin groper, sweetlip emperor and coral trout, creating the third most important fishery in the bioregion (DoF, 2007a). The overall spatial area of the fishing grounds for baldchin groper by the charter industry was relatively consistent throughout the study period, with no significant increase or decrease in area. Any change in high and low catch rate density patches may be a result of localised depletions.

Overall, the ordinary kriging showed that the majority of low catch rate estimates occurred near Perth and further south towards the Bunbury region: this was notably evident in the catch rates for pink snapper and combined all species. These maps showed detail that is not accessible in the catch rate maps (Figure 3.2) as basic statistics are not appropriate enough to characterise the spatial variability (Goovaerts, 1997). In general, fishing behaviour in the charter industry in the West Coast bioregion appears to be different in the northern extent compared to the southern extent. The mean catch rates between 2002/03 and 2007/08 were higher in the northern extent than the southern extent. A contributing factor to this difference may be the result of the distribution of the human population structure within the bioregion. In June 2009, the Australian Bureau of Statistic (ABS) estimated the population of Western Australia to be 2.25 million people of which 74% live in the Perth metropolitan area (ABS, 2010). With the human population density so strongly concentrated in one area, the associated impact on fish stocks may be higher. This may account for lower catch rates in the southern extent of the bioregion as fish stocks are more heavily exploited compared to the northern extent.

The change in the spatial structure of catch rates for all species in the West Coast bioregion in 2005/06 and 2006/07, whilst not conclusive, may be indicative of increased pressure on fish stocks. If local fish stock densities decline, charter operators may be forced to search for new fishing grounds and/or target different species. This change in fleet behaviour may account for the greater amount of variation in the spatial structure of catch rates over shorter distances and may, in this case, account for some of the changes in spatial structure. More positively, the spatial structure of catch rates for all species in 2007/08 appeared to return to what is was prior to 2005/06. In November 2007, the commercial line and gillnet fishing were closed out of the Metropolitan fishing zone, between Lancelin and south of Mandurah, as part of a fishing reform package to ensure sustainability of fish for the future (DoF, 2007b). This change may further improve the spatial structure of the distribution of the species but an extended time series of spatial data would be needed to demonstrate a change.

Studies have shown that demersal catches in the West Coast bioregion are above international benchmark standards, which can indicate that fish stocks are currently being over fished (Wise *et al*., 2007). However there was no definitive evidence to suggest that the change in spatial structure of the indicator species dhufish, pink snapper and baldchin groper was due to increased pressures on these stocks. Nevertheless, it is recommended that further monitoring is undertaken using geostatistical techniques to assess the spatial structure of catch rates beyond this study period. Further analysis may provide a more definitive answer as additional data becomes available.

Geostatistics in fisheries management can provide an understanding of the spatial structures of a sector, and it should be an essential tool, particularly if management strategies include spatial closures and/or restrictions, as it provides a level of detail that other generic analyses cannot show. High-resolution mapping by kriging has been used by fisheries biologists as a tool to forecast accurately the location and the spatial characteristics of an exploited resource (Maynou, 1998). Species with low mobility and those that reside in benthic habitats, are an ideal case for the application of geostatistics (Maynou, 1998), as indicated by the results of this study.

The spatial analyses in this study have provided a level of detail about the structure of the charter industries catch rates for the West Coast bioregion that has not been previously known or explored. It provides a framework for future analysis for other bioregions and areas within those regions, as well as other fisheries. Geostatistical analysis outputs can provide managers with additional tools for ensuring the long-term sustainability of fish stocks and fisheries. Since this study was completed, a two month spatial closure to the recreational (including charter) sector on catching 'high risk' species including the demersal indicator species dhufish, pink snapper and baldchin groper in the West Coast bioregion has been implemented (DoF, 2009). Future geostatistical analyses on the charter industries catch rates could assess the effectiveness of the spatial closure, its direct effect on those key species, and associated altered behaviour of the charter industry.

CHAPTER 4

SOCIAL AND ECONOMIC TRENDS IN THE CHARTER BOAT INDUSTRY OF WESTERN AUSTRALIA

4.1 INTRODUCTION

Since 1992, the Australian government has been committed to endorse the National Strategy for Ecologically Sustainable Development (ESD) which aims at "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and in the future, can be increased" (Department of Environment, Water, Heritage and the Arts, 1992). Increasing demand on fisheries resources and the impact on marine ecosystems has resulted in changes to management objectives with the focus now on the principles of ESD (Department of Environment, Water, Heritage and the Arts, 1992). Under these principles, the gathering of catch and effort data from commercial and recreational (including charter) sectors, together with the collection of the social and economic aspects of fishing and fishing industries, is required to assist decision makers, and therefore provide a platform for long-term sustainability of a fishery (Schirmer & Casey, 2005).

Charter industry exhibit characteristics of both commercial and recreational sectors, whereby operators are paid for a service and are managed under a licensing framework, but their clients adhere to recreational fishing regulations. In contrast to both recreational and commercial sectors, studies on either social and economic and/or catch and effort data on the charter industry have been limited, with most of the literature providing summary statistics or descriptions of regionally-focused studies rather than detailed analyses relevant for management decision-making (refer to Chapters 2 and 3). Without a full suite of detailed catch, effort, social and economic information readily available, the decision-making processes of fisheries managers has an increased risk, as decision may be made without adequate information.

Having social and economic information on fisheries is critical to ensure that ESD policy objectives are met. To date, in Western Australia, minimal work has been done to address social and economic factors in accordance with Ecosystems Based Fisheries Management (EBFM), which has been developed under the principles of ESD (Vieira *et al.*, 2009). The EBFM process is a new initiative and incorporates social and economic factors into management process along with biological and environmental considerations, at both the fisheries and regional levels in Western Australia (Vieira *et al.*, 2009).

The economic rationale for any business is one where an allocation of resources, for example. time, labour and fish stocks, is associated with maximum net economic benefit. This can include revenue earned or non-monetary benefits such as those associated with recreational fishing (Vieira *et al*., 2009). The charter boat industry primarily earns revenue from clients, whilst their clients receive the non-monetary benefits of the trip. The charter industry operates a range of different business types within each bioregion, including extractive and non-extractive activities, but little is known about the social and economic profile of their clientele.

There are many ways to collect social and economic information, including mail, phone, face-to-face surveys and internet/web surveys (Dillman, *et al*., 2009). Mail surveys can be the most cost effective method for surveying a community, as they involve less labour time than asking questions by phone or face-to-face and remove the biases associated with phone or face-to-face surveys, e.g. promoting an answer (Schirmer & Casey, 2005). Therefore a quantitative mail survey of charter clients was undertaken to gain an understanding of the social and economic dimensions of the industry and to deal with the expanse of the coastline in Western Australia along with the distribution of the charter industry.

The aim of this chapter is to provide a social and economic profile of clients from the Western Australia charter industry, as well as provide a financial breakdown of the costs associated with the industries licensing framework and assess the transfer of licenses. Activities undertaken by the clientele and their overall satisfaction are also assessed.

4.2 METHODS

A mail survey was conducted on charter clients during four separate sampling periods over the course of a year (September 2008 – August 2009). Given the small population size of the charter industry (Table 4.1), a census approach was used. The sampling frame encompassed all licensed charter operators in Western Australia. The list of all licensed charter operators in Western Australia was formally requested and purchased through the DoF Licensing section for each mail out. Estimates of charter license fees were extracted from the Fisheries Licensing and Monitoring system (FLAMS) and were current at the end of each financial year. Charter operators have 60 days past the expiry date of their license to pay annual fees, so some revenue can appear in next financial year due to late payment.

The design and testing of the questionnaire was reviewed several times by DoF Staff and Edith Cowan University (ECU) Human Ethics, and the questionnaire was approved by the ECU Human Research Ethics Committee (Appendix G1 and G2). Ten copies of the questionnaire were sent to all licensed charter operators (census) on four separate occasions: 1/9/2008, 1/12/2008, 1/4/2009 and 1/7/2009. In total, 11,270 questionnaires were sent out. Operators were asked to supply the survey to their clients at the end of a trip during the survey period, until all questionnaires were completed, and then post the responses back in reply-paid envelopes for data entry and analysis. Charter operators were provided information about the reason for the questionnaire and instructions on the process to follow (Appendix G3). It is important to note the potential bias in the second sampling frame, as charter operators could select any client on any trip to answer the questionnaire, which may of biased results.

Due to a limited budget, only one reminder letter was sent to operators in each period, asking them again to participate in the survey (Appendix G4). Since the majority of responses were received within the first month after the mail out, each mail out will be referred to by the season in which the completed questionnaires were received.

Non-response bias of individual operators (primary sampling frame) could not be assessed because individual clients (secondary sampling frame) and operators could not be identified. Post survey analysis of charter logbook data (refer to the methods in Chapter 2) assisted in providing information on the actual sample size, those out of scope in the survey (inactive charter operators who could not pass the questionnaire onto clients), and non-response bias calculations (those operators who did not respond in any way) (Table 4.1), as it was not possible to determine these at the start of the survey. In some cases, operators were removed from the survey on request from the operators themselves, and in some cases the license was cancelled or not renewed, thus reducing the sample size over time. Operators were deemed out-of-scope if they were inactive during the survey period, and so they could not pass the questionnaire onto clients. Operators who were active during the survey period, including those who fished and/or those who conducted non-extractive trips such as wildlife observations, were deemed in-scope, as they could pass the questionnaire to clients (Table 4.1). The number of licensed in-scope operators was used in calculating the response rates.

Table 4.1: Sample structure of the mail survey.

Sample structure	**Spring**	**Summer**	**Autumn**	**Winter**
No. of Licensed Operators	310	294	294	294
No. of Licensed Operators sampled	310	276	276	269
No. of Licensed Operators removed	0	18	18	25
No. of Licensed Operators out-of-scope	191	178	169	183
No. of Licensed Operators in-scope	119	116	125	111
No. of Reponses (Operators who completed the survey)	19	6	20	5
No. of Reponses (Operators who made contact but could not complete the survey)	30	35	39	43
No. of Licensed Operators who did not respond (Non- response bias)	70	75	66	63

The number of active operators (in-scope) was extracted from the DoF logbook data (Table 4.1 and 4.2). The total number of active operators per season by bioregion totals more than the number of licensed operator's in-scope (Base sample size, Table 4.1) as a number of operators can conduct charter services in multiple bioregions, and can therefore be counted more than once. Noting not all licensed in-scope operators responded to the survey.

Table 4.2: Number of active operators by bioregion, by season.

No. of active operators per bioregion	Spring	Summer	Autumn	Winter
South Coast	10	9	7	7
West Coast	53	70	51	45
Gascoyne	21	23	36	28
Pilbara/Kimberley	40	19	39	42

Preliminary chi-square testing was calculated to assess the best means of analysing the survey results and whether seasonal and bioregional breakdowns were possible. These initial assessments identified that response rates (completed questionnaires) were statistically different ($p < 0.001$) between seasons and bioregions. Thus, each question from the mail survey was statistically tested by season using chi-square analysis. Where statistically significant differences were present, bioregional chi-square analyses were also performed (Figure 4.1). The only exception was with the targeted species, as the sample size was too small when grouped by season and bioregion, so grouping was considered by bioregion only. Due to the small number of responses received by bioregion in summer and winter, comparisons could not be done for these seasons, but results from these time periods are included in the overall results shown.

4.3 RESULTS

Social and Economic mail survey of charter clientele

An initial sample frame of 310 license holders was surveyed. This was reduced to 269 by the winter mail out as licensed charter operators requested removal from the survey or the license was cancelled/not renewed. The overall response rate varied between seasons and regions, ranging between 4% in winter and 15% in autumn and spring, and between 5% from the West Coast bioregion to 16% in the Pilbara/Kimberley bioregion (Table 4.3).

Table 4.3 Response rates of completed questionnaires by bioregion and season.

Bioregion	**Spring**	**Summer**	**Autumn**	**Winter**	**Response rate**
South Coast	10.0%	11.1%	28.6%	0.0%	12%
West Coast	5.7%	1.4%	9.8%	2.2%	5%
Gascoyne	19.0%	13.0%	11.1%	7.1%	12%
Pilbara/Kimberley	27.5%	5.3%	23.1%	4.8%	16%
Response rate	15%	5%	15%	4%	

In total, 398 questionnaires were completed by clients from 37 licensed operators, who returned the questionnaire at least once during the survey period. In total, 50 operators returned completed questionnaires, thirteen of which returned them more than once during the survey. A total of 43 operators confirmed they were out-of-scope during the survey period as they were not operating and therefore could not distribute the questionnaires to clients, the other proportion of out-of-scope operators were back calculated in post survey analysis. Overall, 44% of respondents came from charter services in the Pilbara/Kimberley bioregion, 25.1% from the Gascoyne bioregion, 21.9% from the West Coast, and 9% from the South Coast bioregion (Figure 4.1). The non-response rate was 58.3%, averaged over the survey period.

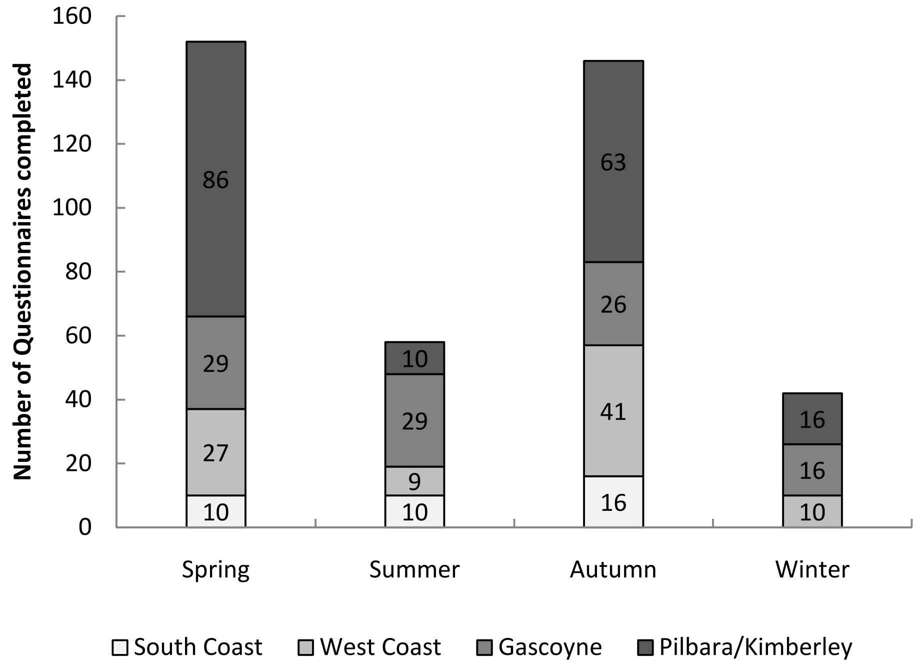

Figure 4.1: Number of respondents who completed questionnaires by bioregion and season.

Age and gender profile of respondents

All age groups were represented by the respondents with 24.4% of the respondents in the 35-44 years age group (Figure 4.2). The least common age class represented in the respondents was 18-24 years old, which accounted for 4.8% of the respondents (note that this age class has a 6 year age interval and 10 years for other age classes). Bioregional analysis of age profiles showed that 34.9% of respondents in the Pilbara/Kimberley were above age 55 years, which contrasted with the Gascoyne and the West Coast bioregions where 44.9% and 55.3% of respondents respectively were 25-44 years old (Table 4.3).

Out of 398 respondents, only six did not answer the gender question. The results showed that, overall, the respondents were dominated by males (71.6%) with only 26.9% of respondents being female.

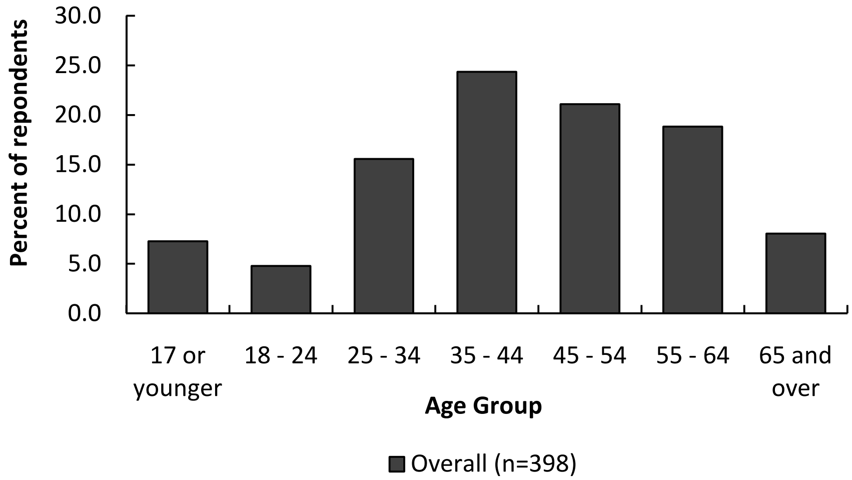

Figure 4.2: Age profile of respondents (n=398).

Table 4.3: Percent of respondents by age and bioregion.

Bioregion	18 - 24	25 - 34	35 - 44	45 - 54	55 - 64	65 and over
West Coast	4.6%	31.1%	24.2%	24.2%	11.4%	0.0%
South Coast	3.3%	10.9%	14.1%	19.6%	21.7%	27.2%
Pilbara/Kimberley	1.1%	7.5%	25.2%	22.2%	26.3%	8.6%
Gascoyne	11.9%	17.9%	27.0%	17.1%	11.1%	7.1%

Geographic profile of respondents

Overall, 92.5% of respondents were of Australian nationality, with the remainder comprising a variety of other nationalities including British, German, American, Japanese, South African, Belgian, Chinese, Swedish, Malaysian, Panamanian, New Zealanders and Dutch. Of the Australians, 67.3% of respondents who provided a postcode (95% of respondents) were from Western Australia (Table. 4.4).

Table 4.4: Place of origin of respondents.

Place of origin	Percent of respondents (n=398)
Western Australia	67.3
Victoria	9.8
New South Wales	7.8
Overseas	4.5
Queensland	2.8
South Australia	2.3
Tasmania	0.5
Did not answer	5.0

Income and payment profiles of respondents

Overall, the income of respondents varied from less than $7,799 to above $104,000 per annum, with 23.6% of respondents stating an annual income between $41,600 and $67,599, and 20.1% of respondents stating an annual income in excess of $104,000 (Table 4.5).

Table 4.5: Income per annum of respondents.

Income per annum	Percent of respondents (n=398)
$1-$7,799	7.3
$7,800 - $20,799	4.3
$20,800 - $41,599	12.8
$41,600 - $67,599	23.6
$67,600 - $83,199	15.3
$83,200 - $103,999	10.8
$104,000 +	20.1
Did not answer	5.8

The price per trip paid by respondents was highly variable, ranging from below $100 to above $500 (Figure 4.3). The price paid for the charter service differed significantly between spring and autumn ($p < 0.001$), and amongst bioregions ($p < 0.001$). If one assumes that, within each price range, the maximum price was paid, then the mean price per trip, based on responses received, was highest for the Pilbara/Kimberley bioregion at $371 per tour and lowest for the South Coast bioregion at $212 per trip. Mean prices for the Gascoyne and West Coast bioregions were $281 and $241, respectively.

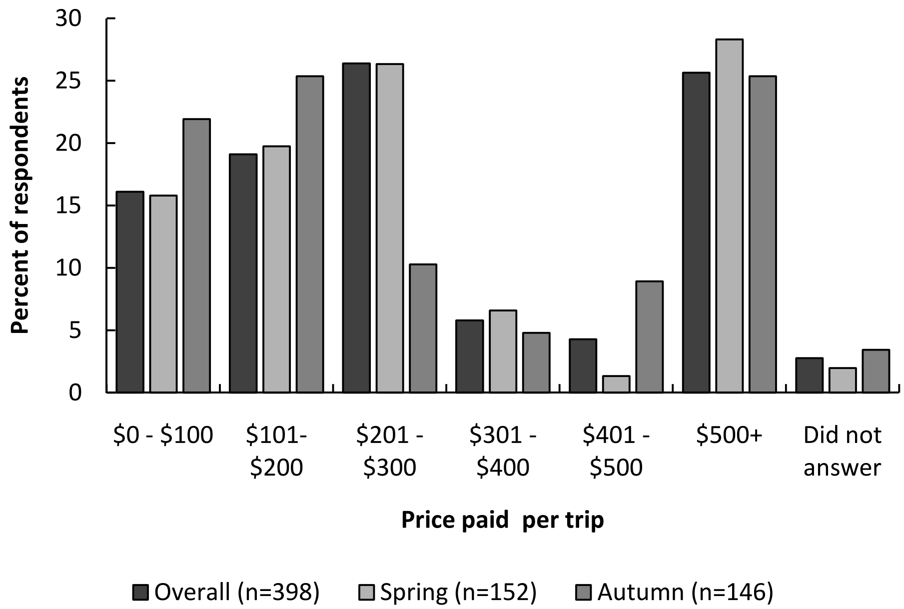

Figure 4.3: Price paid per trip, overall and for spring and autumn.

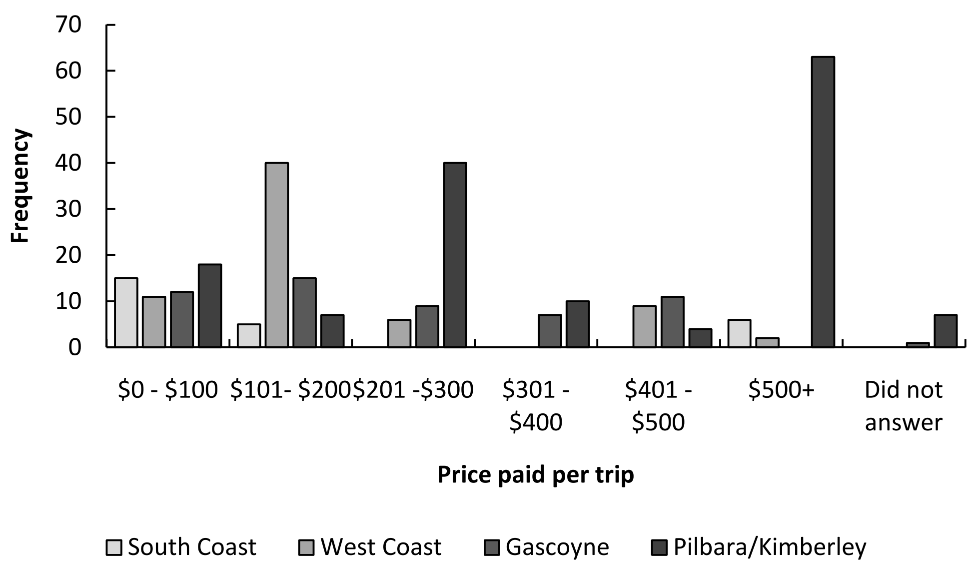

Figure 4.4: The frequency of prices paid per trip by respondents for charter service by bioregion (spring and autumn combined).

Number of Charter Service taken by respondents in the last 12 months

Of the 398 respondents, 17 respondents did not indicate the number of charter services they had used in Western Australia in the past 12 months (Table 4.6). Of those who did

64.3% stated that the charter service they were on was the only one taken in the past 12 months, and 20.9% of respondents had taken between 2 - 3 charter tours. More than 10% of respondents had taken more than 3 charter tours in the last 12 months.

Table 4.6: Number of charter services taken in Western Australia over the last 12 months.

Number of Charter services	**Percent of respondents (n=398)**
1	64.3
2 – 3	20.9
4 – 5	5.0
6 – 8	1.8
9 – 12	1.3
13+	2.5
Did not answer	4.3

Marketing profile and satisfaction of respondents

A total of 396 respondents indicated how they selected their charter service, with only two respondents not completing this question. The most commonly cited reason for choosing a particular charter tour was through word of mouth. The majority of respondents (56.5%) had heard about their charter service through a friend or relative (Table 4.7). Only 16.3% of respondents had been advised by the tourist bureau and 8.0% had obtained the information from the internet.

Table 4.7: Percent of respondents marketing medium for the charter service.

Marketing Medium	**Percent of respondents (n=398)**
Friends and relatives	56.5
Tourist Bureau	16.3
Internet	8.0
Dive Shop	3.0
Newspaper/magazine	2.5
Repeat Customer	1.7
Group Tour	1.7
Hotel Accommodation	1.5
Reputation	1.5
Local Business	1.0
Miscellaneous others <1% (n=15)	5.8
No answer given	0.5

Overall, 76.4% of respondents were very satisfied with their charter service, while a further 11.1% where somewhat satisfied (Table 4.8). Only 6.3% were very dissatisfied with their charter service.

Table 4.8: Overall satisfaction with the charter service.

Overall satisfaction of the charter service	**Percent of Respondents Overall (n=398)**
Very satisfied	76.4
Somewhat satisfied	11.1
Very dissatisfied	6.3
Neither satisfied or dissatisfied	1.3
Somewhat dissatisfied	0.8
No answer given	4.3

Activity profile of respondents

Overall 67.6% of respondents fished during their trip, while 4.3% did not indicate whether they fished or not (Table 4.9). Of those respondents who fished, 53.9% of respondents fished for food, whilst 30.6% fished for sport (catch and release). Other reasons given for fishing included enjoyment, recreation and the experience (Figure 4.5). In addition, 58.7% fished with a rod and reel, while 37.7% fished with a hand line (Figure 4.7).

Table 4.9: Percentage of respondents who indicated they fished on the charter service.

Fishing	**Overall n=398**
Yes	67.6
No	28.1
No answer given	4.3

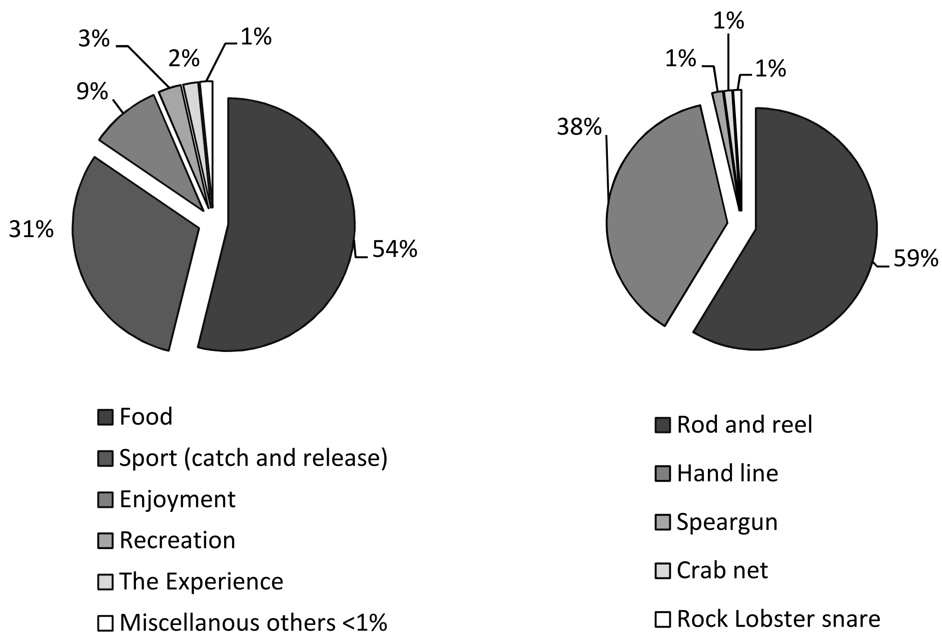

Figure 4.5: Percentage of the reasons for fishing (n=310) and the method used for fishing (n=276) by respondents on charter services.

Respondents identified a total of 47 different common names as target species (see Appendix H for a list of all species). Overall, barramundi was the most sought after fish, with 13.7% of respondents desiring to catch this species. Red emperor and pink snapper were also highly sought after (Table 4.10). Targeted species differed between spring and autumn ($p < 0.05$), and among bioregions ($p < 0.001$).

Table 4.10: Species respondents wanted to catch.

Species respondents wanted to catch	Percent of respondents (n=364)
Barramundi	13.7
Anything	12.9
Red emperor	12.9
Pink snapper	10.4
Dhufish	7.4
Coral trout	4.4
Baldchin groper	2.7
Snapper	2.7
Sailfish	2.5
Narrow barred spanish mackerel	2.5
Blackspot tuskfish	2.2
Mackerel	1.6
Mangrove jack	1.6
Mud crabs	1.6
Queenfish	1.6
Spangled emperor	1.6
Black jew	1.1
Fingermark bream	1.1
Rock lobster	1.1
Threadfin salmon	1.1
Tuna	1.1
Miscellaneous other <1% (n=26)	11.8

With the majority of responses coming from the Pilbara/Kimberley bioregion, it is not surprising that the most popular target species overall have a northern distribution (red emperor and barramundi). An increase in responses from the West Coast bioregion in the latter half of the survey period, reflected an increase in dhufish and pink snapper. A high proportion of respondents were also happy to catch anything. On occasion, respondents wanted to catch species that were not distributed in a particular bioregion, for example, mangrove jacks in the South Coast (Table 4.11). These results should be interpreted with caution.

Table 4.11: Frequency of respondents for the species they wanted to catch from each bioregion (spring and autumn combined due to small sample sizes).

Species respondents wanted to catch	**South Coast**	**West Coast**	**Gascoyne**	**Pilbara/ Kimberley**
Anything	0	5	3	18
Baldchin groper	0	5	0	0
Barramundi	0	0	0	50
Black jew	0	0	0	5
Black marlin	0	0	1	2
Blackspot tuskfish	0	0	2	6
Cod	0	0	0	3
Coral trout	0	1	0	9
Dhufish	0	21	0	0
Fingermark bream	0	0	0	4
Mackerel	0	0	0	4
Mangrove jack	1	1	0	4
Mud crabs	2	0	0	4
NW snapper	0	0	0	2
Perch	0	0	0	2
Pink snapper	0	18	4	2
Queenfish	0	0	0	12
Red emperor	0	0	8	15
Reef fish	0	4	0	1
Robinson seabream	0	0	0	2
Sailfish	0	0	0	3
Seaperch	0	0	0	2
Snapper	0	0	0	5
Spangled emperor	1	0	0	7
Sweetlip	0	0	0	2
Threadfin salmon	0	0	0	3
Tuna	2	0	0	0
Miscellaneous others < 1 (n= 14)	0	1	3	11
Total	**6**	**56**	**21**	**178**

In terms of activities other than fishing, 18.4% of respondents snorkeled and 15.3% were sightseeing (Table 4.12). There was a significant difference in these other activities between spring and autumn ($p < 0.001$), and further analysis showed that those activities also differed among bioregions ($p < 0.001$). In the Pilbara/Kimberley bioregion 50% and

37.3% of other activities were sightseeing and wildlife observation respectively (Table 4.13). In the Gascoyne bioregion, 37.5% of other activities were sightseeing, and in the West Coast, 51.9% of other activities were diving, whilst 56.1% of other activities were sightseeing in the South Coast. In total, sightseeing accounted for 43.2% of activities undertaken other than fishing. Note: in some cases respondents provided more than one answer for activities other than fishing, which increased n.

Table 4.12: Non-extractive activities taken on the charter service.

Non-extractive Activity	Percent of respondents Overall (n=413)
Diving	5.3
Snorkeling	18.4
Wildlife observation	1.7
Sightseeing	15.3

Table 4.13: Non-extractive activities taken on the charter service by bioregion (spring and autumn combined).

Bioregion	Diving	Sightseeing	Snorkeling	Wildlife Observation
South Coast	0.0%	56.1%	2.4%	41.5%
West Coast	51.9%	21.2%	3.8%	23.1%
Gascoyne	2.5%	37.5%	25.0%	35.0%
Pilbara/Kimberley	4.4%	50.0%	8.2%	37.3%

License Transfers

Charter licenses have been transferrable to new owners since 2001. Since then, the highest number of transfers occurred in 2003/04, when a total of 35 charter licenses were transferred (Figure 4.6). Over the six-year period, 155 licenses in total were transferred. In some cases, the same license was transferred multiple times. At a bioregional level, the proportion of transfers was high in the West Coast (31.6%) and Pilbara/Kimberley (28.4%) bioregions (Table 4.14). Other bioregions had some annual movement, but these were small in comparison. The majority of the licenses that were transferred were Fishing Tour Operator (FTOL) licenses, which enable the operator to undertake fishing trips.

A total of just over $1.2 million was collected in licensing fees by DoF between 2002/03 and 2007/08, averaging just over $200,000 per financial year (Table 4.15).

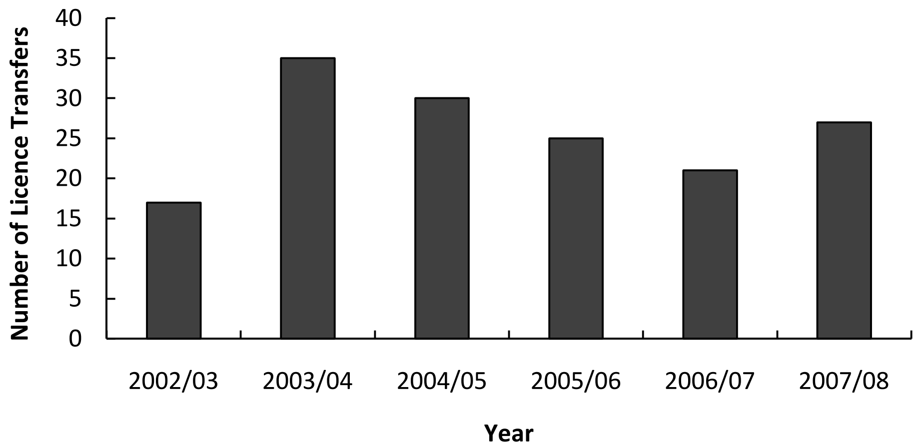

Figure 4.6: Number of Licenses transferred between 2002/03 and 2007/08.

Table 4.14: Number of license transfers between 2002/03 and 2007/08 by bioregion.

Bioregions	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**
South Coast	0	1	2	1	2	2
West Coast	5	11	10	8	7	8
Gascoyne	2	1	4	4	3	4
Pilbara/Kimberley	4	13	7	6	4	10
Gascoyne & West Coast	2	2	1	0	2	0
West Coast & South Coast	0	1	0	1	0	0
Pilbara/Kimberley & Gascoyne	1	1	2	1	0	1
Pilbara/Kimberley, Gascoyne & West Coast	2	4	4	3	3	1
Pilbara/Kimberley & West Coast	1	1	0	0	0	1
All Bioregions	0	0	0	1	0	0

Table 4.15: Total annual licensing fees.

Year	Licensing Fee per annum
2002/03	$222,450.00
2003/04	$169,925.00
2004/05	$231,160.00
2005/06	$206,675.00
2006/07	$182,000.00
2007/08	$220,340.00
Total	**$1,232,550.00**

4.4 DISCUSSION

The mail survey provided a broad overview of the social and economic characteristics and demographics of charter clientele in Western Australia, which will facilitate DoF meeting its ESD policy objectives. One of the key objectives in ESD decision making is effective long and short-term economic, environmental and social and equity considerations (Department of Environment, Water, Heritage and the Arts, 1992). Despite the budget limitations, this survey represents the first broad-scale social and economic mail survey aimed at charter clientele in Western Australia. This survey now provides a baseline for comparisons for future socio-economic studies.

With 76.4% of all respondents very satisfied with their charter experience in Western Australia, this information provides valuable feedback to those charter operators who participated in the survey. Given that over 56% of respondents selected their charter service through a friend or relative, the overall satisfaction of a client's charter experience is important for future business at an industry level. It would appear that the majority of clients go on a charter trip as a one-off event, rather than on a regular basis, with 10.6% of respondents taking more than three charter tours in the last 12 months. Overall, the social characteristics of the charter clients in Western Australia fit closely with other social surveys, for example recreational anglers in Queensland (Sutton, 2006). In the current study, this is partly reflected by the large response from the Pilbara/Kimberley bioregion where barramundi are present, thus influencing the outcome. One key difference between the studies is that charter clients pay directly for their experience, whilst financial outlays are more indirect for recreational anglers.

Responses from the mail survey were dominated by clients on charters in the Pilbara/Kimberley bioregion (44%), which ultimately influenced the outcomes of the survey and added a level of bias to the overall result. This questions how representative are the results of charter clients. Key differences included: the price paid; activities undertaken other than fishing; and the targeted species by respondents. The mean price for a charter in the Pilbara/Kimberley was estimated to be $371 per client for a tour, which was 24% higher than any other bioregions. Several factors may account for the higher price. One factor may be the cost of living, as studies have shown costs to be significantly higher throughout regional Western Australia compared to the Perth metropolitan area. The distance from Perth and the associated transportation costs are the dominant factors in the difference in prices for goods and services (WACOSS, 2009). Also, in 2007/08, an independent economic study estimated the expenditure (including fuel, bait, labour and boat repairs) per client for charter operators in the Kimberley region to be $329 (Econsearch, 2009). These factors may contribute to the higher costs associated with trips in the Pilbara/Kimberley, together with the distances between major town centres. These distance issues may provide an opportunity for charter operators to promote longer stays and overnight accommodation, which they do, as the closest town sites are too far away to offer regular day trip services.

The majority of respondents (67.3%) are presumed to be on intrastate holidays, as they were residents to Western Australia. In 2009, an estimated 500,000 tourists visited both the Pilbara/Kimberley and Gascoyne regions, of which 63% and 78% respectively were residents of Western Australia (Tourism WA, 2009b). Another key factor was the age profile of respondents. A high proportion of the clients in the Pilbara/Kimberley were more than 55 years old, compared to the Gascoyne and West Coast bioregions, where a higher proportion of respondents were 25-44 years old. "Grey Nomads", who are usually couples aged >55 represent the highest proportion of travelers (40%) in Western Australia (Tourism WA, 2009a), and possibly account for the variation in age groups between bioregions. In terms of income, the highest proportion of respondents (23.6%) had an annual income of $41,600-67,599, which equates to the median annual income of Australians of approximately $53,300 per annum (ABS, 2008). The annual income of charter clients, therefore, does not appear to differ from broader society trends.

Charter clients appeared to expect a diversity of activities during each trip. This was particularly evident with sightseeing, which accounted for 43.2% of activities undertaken other than fishing. However, in terms of fishing, 53% of respondents did so for consumption, and the most common method used was a rod and reel. With the majority of responses coming from the Pilbara/Kimberley bioregion, it is not surprising that the most popular target species overall had a northern distribution (red emperor and barramundi). An increase in responses from the West Coast bioregion in the latter half of the survey period coincided with an increase in dhufish and pink snapper, which are species with distributions in that bioregion. These results indicate that the majority of clients appear to have prior knowledge of the species which occur within particular regions and have an expectation of what they want to catch whilst on the charter service. However, many clients were not selective about their target species, as they were targeting anything that they could catch, suggesting that they were expecting a broad fishing experience.

The response rate varied between bioregions, with the highest response rate from the Pilbara/Kimberley bioregion and the lowest from the West Coast bioregion. Response rates were influenced by the season and/or more desirable weather conditions. In the Pilbara/Kimberley and Gascoyne bioregions, responses were lowest in the wet season, and highest in the dry season. The same seasonal patterns occurred in the West and South Coast bioregions, with the exception of summer in the West Coast when response rates fell to 1.4%. Low response rates like this generates a level of uncertainty in the results and questions how representative it is of all charter clients. The variable response rates among seasons and bioregions may be attributed to a range of different factors, but because a non-response survey could not be conducted, these factors remain unclear. With any quantitative survey, there is the possibility that those who complete the survey are not representative of the population if the non-response bias is high (Schirmer & Pickworth, 2005). During the mail survey, there were several major changes to recreational fishing arrangements, which directly impacted on the charter industry, and may have influenced participation in the survey (DoF, 2009). These predominately affected operators in the West Coast bioregion. One of the key announcements for that bioregion was a two-month spatial closure to the recreational (including charter) sector on catching ‘high risk’ species including dhufish, pink snapper and baldchin groper (DoF, 2009). These are amongst the species most commonly retained by the charter industry (refer to Chapter 2), and similarly, results from the mail survey showed that 10.4% and

7.4% of respondents wanted to catch pink snapper and dhufish, respectively. Despite the potential impacts and limitations on the survey, the results provide some useful insights into the socio-economic structure of charter clientele in Western Australia. Many operators expressed their desire to contribute to the survey, but due to their inactive status at that time, they could not participate. This positive feedback was encouraging behaviour should another survey be undertaken in the future.

License transfers within the charter industry were highly variable. Between 2002/03 and 2007/08, there were 155 license transfers, with the highest occurring in 2003/04. The majority of this turnover occurred with licenses that can operate in the West Coast and Pilbara/Kimberley bioregions. It is unclear why this turnover continues, however, it may be due to a number of factors. In a study conducted on the business turnover in the Texas Charter fishing industry, two explanations were offered: increased operating costs for fuel and insurance, and regulatory effects of fisheries management (Ditton and Vize, 1987). Whilst the charter industry of Western Australia has experienced increasing fuel costs since 2002/03 (Department of Commerce, 2010), the DoF has also modified the management of recreational fishing regulations resulting in changes that have impacted on the industry, however this only occurred in the latter part of the study period (DoF, 2009). Since most of these changes have occurred relatively recently, the high rate of license transfers is not completely attributable to these sources. Some turnover in the earlier years may be the result of the implementation of the licensing framework, thus creating regulatory rigor as the industry stabilised and adjusted to the change (refer to Chapter 2). To understand this further, research should be undertaken to ascertain the driving factors that promote charter operators to sell their businesses, this would be best achieved by conducting another survey with the operators themselves.

The annual economic value of the charter boat industry is not presently known however, what is known is the revenue that is generated from the charter license framework at the end of each financial year. The license fee paid by operators was dependent on the license category type (Chapter 1, Table 1.0), passenger capacity and the number of boats on a license. On average, a total of $200,000 was collected through the charter licensing framework each financial year over the 6-year period, and from this, DoF was required to manage and maintain policy, provide administration, maintain licenses, provide mechanisms for compliance and education, and undertake research and monitoring for the industry. In response to a recent change in recreational angling in Western Australia, the implementation of a new license for recreational anglers fishing from a boat commenced in March 2010. To avoid charter operators having to ensure that each of their clients has an appropriate license enabling them to fish, the DoF announced in June 2010 that the Minister for Fisheries had approved a new licensing fee for the charter industry. These new fees incorporate the forecast fees the charter industry would have been required to collect from each charter client who did not hold a valid recreational fishing from a boat license. This change will see the gross annual fee more than double in the coming 2010/11 financial year (DoF, 2010). This ensures that the charter industry accounts for their proportion of the new recreational fishing from boat license fee. In addition, the Minister announced that the charter industry would be formally reviewed by the DoF. This review is due for completion by the end of 2010 (DoF, 2009). Information gained from the current study will help facilitate that review.

CHAPTER 5

SUMMARY AND MANAGEMENT IMPLICATIONS

The charter boat industry of Western Australia is a developing fishery with a licensing framework system since only 2001 (Johnson, 2005). Overall the results presented in this thesis show that catch and effort trends for the charter industry have been relatively stable throughout the 6-year study period, with the exception of the Gascoyne bioregion. Each bioregion is distinctive, all having a diverse array of targeted marine species and clientele characteristics. The charter industry is strongly seasonal, with greater activity in the winter (dry season) in the tropical regions and summer in the temperate regions.

Unlike other bioregions catch rates in the Gascoyne bioregion increased over the study period, which was the only significant change identified in the analyses across all bioregions. This increase in catch rates was not reflected in the actual catches in the bioregion. In exploring this further, catch rates from the commercial sector, over the same time period and in the same bioregion, had an increasing trend, and then subsequently declined by 2007 (Jackson & Lai, 2007/08). Unfortunately, there are no recreational data available for complete comparisons. However direct comparisons, are not truly accurate as the charter industry measures its effort in terms of clients, whilst the commercial sector measures effort by hours and gear types. Despite this a likely cause of increasing catch rates in the Gascoyne bioregion from the charter industry may be the technology creep, as well as the presence of a relatively stable fishing fleet, compared to other bioregions and knowledge on fishing hot spots from prior fishing events. Over the study period the number of clients fishing in the Gascoyne bioregion decreased, but the catch remained stable, so even with less clients fishing, the effective ability to maintain catch levels may indicate an increase in efficiency. Effective effort can increase through the adoption of new technologies such as GPS, more powerful boats and mechanical reels. These factors can cause misleading results in catch rate analyses, as effort is reduced leading to inflated catch rates (Wise *et al.,* 2007). Whilst these results depict the effect of increases in technology to commercial fishing fleets, it could be assumed that advances in technology would also feed into the recreational sector, including the charter industry as they compete for fish stocks. The monitoring of new fishing techniques to identify the effects of 'technology creeps' is important and highlights the need for constant improvement and modification of data collection techniques to ensure these changes are captured. The evidence of efficiency gains in other bioregions was not observed in the data, however this may have been masked by the high variability of license transfers.

The charter boat industry exhibits characteristics of both commercial and recreational sectors. Charter boat operators are paid for a service and are managed under a licensing framework, but their clients must adhere to a set of recreational fishing regulations. This can place limitations on the industry from both sides. Also, given the small size of the charter fishery in comparison to others and the relatively minor income to DoF, the industry is likely to be placed as a lower priority in terms of resourcing for management, research and compliance. The developing nature of the fishery may attribute to the substantial latent effort that currently sits in the industry, where the average proportion of inactive operators ranged from 41.4% to 54.7% over the study period. In addition, the industry was dominated by only a few ‘successful’ operators, with the top ten operators in each bioregion accounting for between 58% and 100% of the total retained catch. This unmanaged latent effort, has large implications for the fishery, as it can allow for catch and effort within the charter industry to increase rapidly. Should this occur, there would currently be limited management options available, to immediately regulate an unexpected change. A sudden increase in effort and/or greater efficiency, not only increases the pressures on fish stocks, but also increases the pressure on operators, as they compete for clients. Of the active fishing charter operators, 31% reported between one and ten fishing trips each financial year, which opens up the possibility for the capacity of latent effort to increase also. The number of license transfers within the charter industry was also highly variable. In a study conducted on the business turnover in the Texas charter fishing industry, two explanations were offered: increased operating costs for fuel and insurance, and regulatory effects of Fisheries management (Ditton & Vize, 1987). It is essential that latent effort is effectively managed to ensure the long-term sustainability, of not only the industry, but the fish stocks and ecosystems they rely on. The implementation of the licensing framework was justified as a precautionary approach of 'capping' activity until the relative impact of fishing activities on fish resources and fish habitat is established (DoF, 2000). However, the evidence of latent effort in the fishery suggests that further steps need to be taken to reduce some potential risks. It is also recommended that independent on-site validation of charter catch and effort data should be undertaken to verify the accuracy of the data, not only from a compliance perspective, but from a research perspective. This requirement is particularly important, given that current management decisions are made using the existing dataset, and these decisions can directly impact on the charter industry, as well as the recreational and commercial sectors.

The social and economic survey showed that the charter industry is heavily reliant on word of mouth through their clients, and with the vast majority of these clients residing in Western Australia, highly populated areas are extremely important. The Perth Metropolitan area is home to 74% of the state's 2.25 million residents (ABS, 2008) and hence it is the busiest bioregion for the charter industry. Unfortunately, these populated areas are also where the lowest catch rates occur as shown by the spatial maps of kriging catch rate estimates, where they were consistently lower in the southern extent of the West Coast bioregion. This quantitative assessment of the spatial continuity/disparity of catch rates highlighted the variability in the spatial structure. Analysis of the key indicator species, pink snapper, baldchin groper and dhufish, highlighted changes in spatial structure within the West Coast bioregion, independent to each species. Ordinary kriging estimates of catch rates showed high-density areas (patches) alternating with low-density areas, which could indicate localised depletion. In addition, there was also competition with the commercial and traditional recreational sectors, with over 50% of all recreational boats in Western Australian registered in the Perth Metropolitan area (Department of Planning and Infrastructure, 2007). However, importantly, the charter industry only accounts for a small proportion of the total catch, compared to other sectors, despite the fact that there has been some evidence that this proportion has increased in relation to pink snapper catches.

Within the charter industry, targeted species are likely to be strongly influenced by client needs, wants and expectations. Whilst information on target species is not collected by the DoF, catch trends in each bioregion suggest there is an element of targeting for species such as pink snapper, dhufish, bight redfish, barramundi, spangled emperor, sweetlip emperor, fingermark bream, red emperor, mangrove jack and western rock lobster. Outcomes from the social and economic study reinforced this, with clients naming over 47 different targeted species, with the majority of clients appearing to have prior knowledge of species within a particular region. The high number of fish released by the industry raises concerns some species such as dhufish and pink snapper, can suffer from high levels of post-release mortality due to barotrauma (St John and Syers, 2005). Thus, while there is a common misconception in recreational fishing that if fish are released, their populations will not decline (Policansky, 2007), releasing of fish from several key species in the charter industry of Western Australia will still lead to increased mortality. It is essential that release mortality rates of a wider range of species are estimated to fully understand the associated impact releasing fish has on stocks, not just by the charter industry, but also the commercial and recreational sectors.

Some positive changes are occurring in the charter industry, with recent increases in licensing fees in response to the implementation of a new license for recreational anglers 'fishing from a boat'. This will result in more funding for management and a management review of the industry. This thesis provides important information for this upcoming review of the fishery. The removal of latent effort should allow the current active operators to operate with greater business confidence and may encourage them to organise a state-wide representative group for the industry. Whilst there is currently a Charter Boat Owners & Operators Association in Western Australia, it is seemingly disjointed, with many charter operators not part of this association. This is perhaps not surprising given the number of license transfers. More importantly, the operators themselves are diversifying their business to undertake both extractive and non-extractive trips as seen across all bioregions as well as clients' expectations that they would participate in more than one activity whilst on a charter trip. This is particularly important, as management responds to increasing pressures on fish stocks by implementing spatial closures as a way of reducing effort and allowing stocks to recover. With the DoF rebuilding demersal stocks in the West Coast bioregion, catches may in turn increase in the future, thus further enhancing business prospects. Geostatistical analysis is likely to become an essential tool, particularly when the management strategies include spatial closure and/or effort restrictions. The analysis technique can monitor the spatial changes in fishing fleets and fish stocks, as areas are closed and effort is shifted to the edges and beyond those closed areas.

With the charter boat industry currently under review the future management of the industry remains unclear. Consideration of a revision of the current licensing framework seems a necessary element given that historically one license category has never even been used since it was first created. There is also a need for clear decisions to be made on whether the industry should be managed entirely by the DoF. One could assume that the non-extractive side of the industry is better managed by agencies that specialise in Tourism and/or other government agencies with vested interests. Given that the DoF is responsible for: (1) the conservation of marine and freshwater species in Western Australia; (2) the protection of the environment, including associated food chains; and (3) ensuring that the exploitation of these resources is undertaken in a sustainable manner (DoF, 2006). If the DoF has clear management objectives to sustain fish stocks and environment, then perhaps those charter operators, who carry out sightseeing trips and wildlife observations, do not clearly fit within the current licensing framework system, which has its major activity set as an extractive fishery.

This thesis provides the first substantial examination of the charter industry in Western Australia and provides important information for better management of the industry from an ecological, economic, social and governance perspective. While this thesis attempted to cover all these areas, it could not cover all areas in detail. Thus, the opportunity exists for future research in the area, including: the impact of charter boat industries - Australia wide; release mortality rates of a wider range of species; independent on-site validation of charter catch and effort data; and a more detailed social and economic study of charter operators. It is essential that the charter industry of Western Australia is continually monitored by the DoF, as it provides quantitative information that may assist in ensuring the long-term sustainability of fish stocks and the industry.

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7. APPENDIX

Appendix A – Management framework for the charter industry throughout Australia

Table A: Each States and Territories management framework of the charter industry.

Jurisdiction	**NSW**	**VIC**	**TAS**	**SA**	**WA**	**NT**	**QLD**
Management Regime	Yes since 2000	No	Planning stages	Yes	Yes since 2001	Ability to grant a license under the Act.	Ability to grant permits under the Act
Number of charter operators (subject to change)	Total 276	Anecdotally between 60 & 80	Anecdotally 30	Anecdotally less than 200	Total 309	Anecdotally 140	387 notional limit of 500
Catch & Effort reporting	Mandatory Details of each trip recorded and submitted monthly	N/A	Mandatory	Mandatory Details of each trip recorded and submitted monthly	Mandatory Details of each trip recorded and submitted monthly	Mandatory Details of each trip recorded submitted monthly	Mandatory Monthly return only
Application of recreational fishing rules	Participants bound by recreational rules	Yes	Participants will be bound by recreational rules	Participants bound by general recreational regulations	Participants bound by recreational bag, size and possession limits	Participants bound by recreational rules	Participants bound by recreational rules

Appendix B – Current "indicator species identified by the Department of Fisheries (DoF, 2011)

Bioregion	**Suite**				
	Pelagic	**Offshore demersal**	**Inshore demersal**	**Nearshore**	**Estuarine**
Pilbara/Kimberley (North Coast)	Spanish mackerel Grey mackerel	Ruby snapper Eightbar grouper	Red emperor Goldband snapper Rankin cod Blue spotted emperor Brown stripe snapper	Kind threadfin Blue threadfin	Barramundi
Gascoyne	Spanish mackerel Grey mackerel	Ruby snapper Eightbar grouper	Pink snapper Goldband snapper Spangled emperor	Pink snapper Tailor Whiting species Garfish	N/A
West Coast	Samson fish Spanish mackerel	Hapuku Blue-eye trevalla Eightbar grouper	W.A dhufish Pink snapper Baldchin groper	Australian herring Tailor Whitebait Whiting species Garfish	Black Bream Cobbler Perth herring
South Coast	Pilchard Blue mackerel Samson fish Yellowtail scad	Hapuku Blue-eye trevalla Eightbar grouper	Bight redfish Blue groper Blue morwong Pink snapper	Australian herring Australian salmon Sea mullet Whiting species	Black bream Cobbler

Appendix C1 – Daily trip return sheet, version 1

Trip Return Sheet

Boat		Vehicle	
Skipper		Driver	
Boat name		Vehicle	
SPV number		TC number	

Trip details

Date / /	Clients	Start time (24hr)	Finish time (24hr)
Departure point		Arrival point	

Weather

Wind strength	1 calm	2 light	3 moderate	4 strong	5 gale	Wind direction
Sea state	1 calm	2 slight	3 moderate	4 rough	5 very rough	
Cloud cover	%	Rainfall	1 nil	2 light	3 moderate	4 heavy

Activities

	Fishing	Diving	Snorkelling	Wildlife observation	Sightseeing
Activity time (hrs)					
Block location					
Fishing effort	lines	people	people	Wildlife observed	Number
Catch retained (Y/N)					

Fish captures

Common name	Kept	Released	Lengths (mm)	Weights (g)

I certify that the information on this form is correct	signature	date

Appendix C2 – Daily trip return sheet, version 2

Daily Trip Return Sheet

Boat		**Vehicle**	
Skipper		Driver	
Boat name		Vehicle	
SPV number		TC number	

Trip details

Date / /	Clients	Start time (24hr)	Finish time (24hr)
Departure point		Arrival point	

Weather

Wind strength	1 calm	2 light	3 moderate	4 strong	5 gale	Wind direction
Sea state	1 calm	2 slight	3 moderate	4 rough	5 very rough	
Cloud cover %	Rainfall	1 nil	2 light	3 moderate	4 heavy	

Activities

	Fishing	Diving	Snorkelling	Wildlife observation	Sightseeing
Activity time (hrs)					
Block location					
Depth (metres)				Wildlife observed	Number
Fishing effort	lines	people	people		
Catch retained (Y/N)					

Fish captures

Common name	Kept	Released	Lengths (mm)	Weights (g)

I certify that the information on this form is correct	signature	date

Appendix C3 – Daily trip return sheet, version 3

DAILY TRIP RETURN SHEET

Date	/ /	Licence No. e.g. (FT... or AE... or RFT...)		

BOAT		VEHICLE	
Skipper		Driver	
Boat Name		Vehicle	
SPV Number		TC Number	

TRIP DETAILS

Clients		Start Point		Finish Point	

Was this day a part of a tour in which you stayed overnight? (Tick) YES ☐ NO ☐

TOURING CHARTERS
(Non-Extractive Activities: e.g. Wildlife observation (whale watching, sight seeing etc)

	Wildlife Observation	Sight seeing	Diving
Activity time (hrs)			
Block Location (Refer to Map)			

FISHING CHARTER
(Extractive Activities: Catching/releasing fish)

	Fishing	Diving	Snorkelling
Hours Fished			
Block Location (Refer to Map)			
Fishing Effort	Lines	People	People
Depth (metres)			

AQUATIC ANIMALS KEPT AND/OR RELEASED

Species/Common Name (Record all species)	Total Kept	Total Released	Length (mm) (Only those kept)

I certify that the information on this form is correct	Signature	Date
	Print Name	Phone No.

Appendix C4 – Daily trip return sheet, version 4 and current form

Tour Operators Return Book

Daily Trip Return Sheet

TO

Date	/ /	Licence No. e.g. FT…RFT… AE…

BOAT/VEHICLE DETAILS	
Skipper/Driver Name	
Boat /Vehicle Name	
SFV/TC Number	

TRIP DETAILS		
Total No. of Clients	Start Point	Finish Point
Was this day part of a trip in which you stayed overnight? Yes ☐ No ☐	If yes, provide GPS co-ordinates for overnight location. Lat (ddmm.mmm)	Long (ddmm.mmm)

PROTECTED SPECIES INTERACTION		
Have you had an interaction with a protected species? Yes ☐ No ☐	If yes, was the species released alive? Yes ☐ No ☐	
Species:	GPS co-ordinates: Lat (ddmm.mmm)	Long (ddmm.mmm)
Comments:		

TOURING CHARTER (Non-extractive activities e.g. wildlife observation (whale watching etc))

	Sightseeing	Diving	Snorkelling	Wildlife Observation	Other (pls specify)
Activity Time (Hrs)					
Block Location					

FISHING CHARTER (Extractive Activities – Catching /Releasing of Aquatic species)

	Fishing	Diving	Snorkelling
Activity Time (Hrs)			
Block Location			
GPS co-ordinates (Compulsory for marine parks & reserves)	Lat (ddmm.mmm) Long (ddmm.mmm)	Lat (ddmm.mmm) Long (ddmm.mmm)	Lat (ddmm.mmm) Long (ddmm.mmm)
Fishing Effort (No.)	Lines	Clients	Clients
Depth (metres)			

AQUATIC SPECIES KEPT AND/OR RELEASED

Species/Common name (Record all Species)	Total Kept	Total Released	Length (mm) (only those kept)

I certify that the information on this form is correct.	Signature	Date
	Print name	Contact Number

Appendix C5 - Western Australian Tour Operators Return Book Explanatory Notes

WHY WE NEED THIS INFORMATION
The Department of Fisheries Western Australia needs this information to properly manage the states' fisheries. Accurate information on fisheries helps the agency make good decisions in regard to fisheries management, which ultimately benefits you.

THE INFORMATION YOU GIVE US IS CONFIDENTIAL
All information supplied to the Department of Fisheries is treated as strictly confidential and will only be released publicly in a summarised form, which does not identify individual operators.

WHAT YOU HAVE TO DO
The master of the vessel, authorisation holder (or their agent) must complete tour operator daily trip returns and a monthly summary for each month's activity. You must also complete a return notifying the Department even when no activity was undertaken, this may be done each month using a separate return.

WHEN YOU HAVE TO
Returns must be lodged not later than the 15th day of the following month.

SEND YOUR RETURNS TO
The Department of Fisheries WA in the bar-coded reply paid envelopes supplied or by addressing an envelope:
Department of Fisheries
PO Box 20
NORTH BEACH WA 6920

If you need any help completing these returns, please ring the tour operator returns officer on (08) 9203 0111.

New books will normally be posted to you, but new books may be obtained by contacting the returns officer. You may fax the returns to (08) 9203 0199, although you still must send the originals.

You are required by law to fill in these forms. Under the Fish Resources Management Regulations 1995, regulations 64 and/or 128E, a person involved in tour operator activity must submit complete and accurate returns, on the forms approved by the Chief Executive Officer. In the Fish Resources Management Act 1994 the term "Fish" means an aquatic organism of any species (whether alive or dead) and includes Sharks, rays, molluscs (e.g. shells, abalone, squid etc), crustaceans (e.g. rock lobsters, crabs etc) corals, sponges, sea squirts and algae; and b) a part only of an aquatic organism (including the shell or tail), but does not include aquatic mammals, aquatic reptiles, aquatic birds, amphibians or (except in relation to Part 3 and division 1 of Part II) pearl oyster.

Tour operator returns are required to be up-to-date at the time applications are lodged with the Department of Fisheries Licensing Branch for the renewal, transfer and variation of Tour Operator Licences. Applications will not be considered unless returns are fully up-to-date. Failure to submit these returns on time, or the entry of any false or misleading information, constitutes an offence. This may result in the issue of an infringement notice, cancellation, suspension for a period of time or non-renewal of your authorisation and/or make you liable to prosecution with a penalty on conviction of up to $5,000 ($10,000 in case of a company). The recording of three convictions against a licence in any tenyear period will result in an automatic cancellation of that authorisation.

THE DAILY TRIP RETURN SHEET

The daily trip return sheet must be completed prior to the end of each tour. For extended tours of two or more days, a separate daily trip return sheet must be completed for each day. Numbered sheets are provided in duplicate - the plain top copy must be returned to the Department of Fisheries and the coloured copy remains in the book for reference purposes. It is important that the card flap attached to the back cover of the return book is tucked under the sheet being used - this prevents marking the underlying sheets.

If there is insufficient space on one sheet to enter details for fish caught during a tour, then the next sheet should be used with a note to the effect that multiple sheets were used on that trip. If you fish in more than one block location you are encouraged to provide catch details for each block, by also providing details on a separate daily trip return sheet. An example of a completed daily trip return sheet can be found in front of the daily trip return sheets.

HOW TO FILL IN THE DAILY TRIP RETURN SHEET

Date - Include the day, month and year of trip

Licence No. - Enter your Department of Fisheries licence number, for example FT4L89 or RFTB118 or AE5L10.

Skipper/Driver Name - Enter the full name of the person responsible for the vessel/vehicle on the trip.

Boat/Vehicle Name - Enter the full vessel name and/or the vehicle type used on the trip.

SPV/TC Number - Provide the surveyed passenger vessel number (SPV) and/or the transport commission (TC) number, which is allocated by the Department of Planning and Infrastructure.

Number of clients - Enter the total number of clients who were on the trip. Include all clients even if they do not actively participate in activities.

Start point- refers to the location at which the trip for that day begins. If the trip includes an overnight stay then the start point for the next day will be the finish point from the previous day. For example if your start point is Fremantle Fishing Boat Harbour and the finish point for that trip (day) is Rottnest Island, and you stay overnight, then the start point for the next trip (day) will be Rottnest Island.

Finish point - refers to the location at which the trip for that day ends. Refer to above for an explanation of overnight stays.

Was this part of a trip in which you stayed overnight? - Tick the appropriate box yes or no. An overnight trip refers to a trip where clients stay overnight on the vessel.

If yes, provide GPS co-ordinates for overnight location. This is a compulsory field for overnight stays in Conservation and Land Management Act marine parks and reserves. Refer to the Department of Environment and Conservation for details on marine parks and reserves. Provide the latitude, degrees & decimal minutes (ddmm.mmm) and longitude (ddmm.mmm) for the overnight stay, for example 30°21.150' 115°21.000'.

Protected species interactions - The implementation of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) means that you now need to monitor any interactions with all listed marine and migratory species and threatened species in State and Commonwealth waters. This includes all whales, dolphins, dugongs, sea turtles, seals, sea lions, pipefishes, seasnakes, some sharks and ray species and many species of seabird. For a full list go to the website http://www.environment.gov.au, and follow the links. Please be aware that the incidental take (to catch, interfere or disturb) of a protected species is not an offence whilst undertaking an approved activity such as fishing. All incidental take must be reported to the relevant state or federal body.

Have you had an interaction (catch, interfere or disturb) with a protected species? - Tick the appropriate box yes or no. This refers to all activity types including fishing, diving, snorkeling, wildlife observation, sightseeing and/or any other activity specified where an interaction (catch, interfere or disturb) with a protected species has occurred.

If yes, was the species released alive? Tick the appropriate box yes or no. For example if while fishing you caught a grey nurse shark on a handline, you would write "grey nurse shark" in the space called species. Then, in the comments underneath, write "cut line to release grey nurse, it swam off strongly" or whatever was the outcome of the interaction. Please be specific was it alive or dead?

GPS co-ordinates - Provide the latitude (ddmm.mmm) and longitude (ddmm.mmm) of the specified protected species interaction.

Touring charter refers to a trip which is non-extractive and/or a combination of activities undertaken. Sightseeing is observing the landscape and geographical features. Diving is diving using compressed air without attempt to capture fish. Snorkeling is diving or surface swimming without compressed air. Wildlife Observation is watching wildlife without attempt to capture. Other is a new section to allow previously unspecified activities to be recorded (for example surfing), in the space provided.

Activity time - Activity time is the total time (hours) involved in that specific activity, which excludes travel and meal time.

Block Location - Using the maps provided by the Department of Fisheries, record the location where the activities occurred using the 5x5 nautical mile blocks. The numbers of the block should be written first followed by the letters, for example “61BN”. If you were active in more than one block, specify the block where you spent the most amount of time or provide trip details on a separate daily trip return sheet.

Fishing Charter refers to a trip where it is extractive and/or a combination of activities were undertaken and an attempt was made to catch and/or release fish (refer page 1 for the definition of fish). Fishing is fishing with a line, net, pot or allowed method.

Diving is diving utilising compressed air and attempting to capture fish, for example using a rock lobster hand held snare.

Snorkeling is diving or surface swimming without compressed air and attempting to capture fish, for example using a spear.

Activity time - Activity time is the total time (hours) involved in that specific activity, which excludes travel and meal time. GPS co-ordinates (Compulsory in marine parks and reserves) Provide the latitude (ddmm.mmm) and longitude (ddmm.mmm) where the fishing, diving and/or snorkeling activity occurred, and if an attempt was made to catch and/or release fish.

Block Location - Using the maps provided by the Department of Fisheries, record the location where the activities occurred using the 5x5 nautical mile blocks. The numbers of the block should be written first followed by the letters, for example “61BN”. If you were in more than one block, specify the block where you spent the most amount of time or the preferred option is to provide separate trip details on another daily trip return sheet, specifying the fish species caught/released in that particular block.

Fishing Effort - refers to the number of lines/pots used by clients when fishing, and the number of clients diving and/or snorkeling.

Depth - Record the fishing depth, in metres for the location where most fish were caught.

Aquatic species kept and/or released - Record catch/release details for all aquatic organisms including fish, crabs, lobsters, shellfish, squid and octopus, edible or not. Identify fish using species and/or common name names from the WA Museum publications “Sea Fishes of Southern Australia”, “The Marine and Estuarine Fishes of South-Western Australia”, “The Marine Fish of Tropical Australia and South-East Asia” or refer to the Department of Fisheries species identification guides.

Total kept - Enter the total number of fish kept per species. With fish caught and used as bait, record them as kept fish.

Total released - Enter the total number of fish released per species.

Length Record - the individual length of all or a representative sample of fish kept. If only a sample of the catch is to be measured, then select randomly, do not measure the biggest or smallest. Record length in millimeters (mm), with fish made as long as possible (nose to tip of tail). Other organisms should be measured as per minimum size requirements.

Certify the correctness of the information after completing the daily trip return sheet, please sign, print your name, date and provide a contact phone number. The contact phone number is important because if there is a query about information provided the correct person can be contacted.

Appendix D- Length to weight relationships

Table D: Length/weight relationship equations used to estimate biomass

Common name	Scientific name	Equation	Reference	Units
Baldchin groper	*Choerodon rubescens*	$LnW=2.980LnTL-10.581$	Fairclough, D. Phd theses 2005	*mm and g*
Barramundi	*Lates calcarifer*	$W(kg)=1.07x10^{-2}(TL/10)^{3.03}$	Vovlich, L. & Appelbaum, s. 2001	*cm and kg*
Fingermark Bream	*Lutjanus johnii*	$W=0.0000199217TL^{2.9422}$	Newman, S.J. Unpublished 2005	*mm and g*
Silver Bream	*Rhabdosargus sarba*	$W=0.0000241TL^{2.932}$	Hesp, A. Phd theses 2003	*mm and g*
Chinaman fish	*Symphorus nematophorus*	$W=0.0303(TL/10)^{2.874}$	Letourneur, Y.M *et al.*1998	*mm and g*
Chinaman cod	*Epinephelus rivulatus*	$W=0.0000104TL^{3.042}$	Mackie, M. Unpublished 1999	*mm and g*
Breaksea cod	*Epinephelides armatus*	$W=33.938e^{0.0085TL}$	Eastman, A. 2001	*mm and g*
Spangled emperor	*Lethrinus nebulosus*	$W=0.00003451TL^{3.042}$	Marriot, R. unpublished 2009	*mm and g*
Sweetlip emperor	*Lethrinus miniatus*	$W= 0.0066TL^{3.2767}$	Kulbicki et al. 2005	*cm and g*
Blue-spotted Emperor	*Lethrinus punctulatus*	$W=1.287 \times 10^{-8} TL^{3.0881}$	Stephenson & Mant 1999	*mm and kg*
Blue-lined emperor	*Lethrinus laticaudis*	$LNW=3.0244LnTL-11.234$	I.Keay unpublished, data from Ayvasian *et al*. 1999	*mm and g*
Estuary cod	*Epinephelus coioides*	$LNW=3.023LNTL-11.246$	Pember *et al.* 2005	*mm and g*
Pink snapper	*Pagrus auratus*	$W=0.0467727((TL-0.7)/11.79)^{2.781}$	Moran & Burton 1990	*mm and g*
Queen snapper	*Nemadactylus valenciennesi*	$W =3.808 \times 10^{-6}TL^{3.175}$	Taylor & Willis 1998 for *Nemadactylus douglasii*	*mm and g*

Bight redfish	*Centroberyx gerrardi*	W= 0.00006495 $TL^{2.761}$	Williamson, P. unpublished 2007	*mm and g*
Swallowtail	*Centroberyx lineatus*	W= 0.00006495 $TL^{2.761}$ Bight redfish equation	Williamson, P. unpublished 2007	*mm and g*
Sea sweep	*Scorpis aequipinnis*	W =7.626 x $10^{-6}TL^{3.136}$	Taylor & Willis 1998 for Scorpis lineolatus	*mm and g*
Sergeant baker	*Aulopus purpurissatus*	W=$00001264TL^{3.012}$	Steffe et al. 1996	*cm and kg*
WA dhufish	*Glaucosoma hebraicum*	W=$0.00004201740TL^{2.856}$	Hesp et al. 2002	*mm and g*
Western foxfish	*Bodianus frenchii*	LnW=2.986LnTL-10.857	Cossington, S. 2006	*mm and g*
Red emperor	*Lutjanus sebae*	W=$0.00002051FL^{3.0147}$ TL=1.0654FL+3.5947	Newman, S.J. & Dunk, I. 2002	*mm and g*
Harlequin fish	*Othos dentex*	W=$0.000429TL^{2.4532}$	Telfer, C.F. unpublished 2006	*mm and g*
Coral trout	*Plectropomus leopardus*	LnW=3.12763LnTL-11.98092	How, J. unpublished 2009	*mm and g*
White blotched rankin rockcod	*Epinephelus multinotatus*	W=$0.932x10^{-8}TL^{3.0924}$	Stephenson, P. & Mant, J. 1996	*mm and kg*
Narrow barred Spanish mackerel	*Scomberomorus commerson*	W=$3.3992x10^{-9}FL^{3.1207}$ TL=42.74+(1.06FL)	Lewis, P. unpublished 2002	*mm and kg*
Mangrove jack	*Lutjanus argentimaculatus*	W=$7.10x10^{-6}(TL/10)^{3.18}$	Torres, F. 1991	*mm and kg*
Saddle-tailed seaperch	*Lutjanus malabaricus*	W=$2.348x10^{-5}FL^{2.9279}$ FL=2.85164+(0.96094xTL)	Newman, S.J. 2002	*mm and g*
Goldband snapper	*Pristipomoides multidens*	W=$2.483x10^{-5}TL^{2.9501}$	Newman, S.J. & Dunk, I. 2002	*mm and g*
Giant trevally	*Caranx ignobilis*	W=$0.0202(FL/10)^{3.0}$ FL=0.86xTL	Pauly, D. *et al.* 1996	*mm and g*
Golden Trevally	*Gnathanodon speciosus*	W=$0.0194(FL/10)^{3.008}$ FL=TLx0.86	Letourneur, Y.M *et al.* 1998	*mm and g*
Skipjack trevally	*Pseudocaranx dentex*	LnW=2.992LnTL-11.331	Farmer *et al.* 2005	*mm and g*

Samson fish	*Seriola hippos*	$W=0.0172349(0.92TL)^{2.921}$	Mackie, M. Unpublished 2003	*mm and g*
King george whiting	*Sillaginodes punctata*	$W=0.0000011TL^{3.29}$	Gaughan *et al*. 2006	*mm and g*
Australian salmon	*Arripis truttaceus*	$W=0.0000013TL^{3.36}$	Gaughan *et al*. 2006	*mm and g*
Moses perch	*Lutjanus russelli*	$W=0.00001867FL^{2.9730}$ $TL=3.3597+1.0675FL$	Newman, S.J. 2002	*mm and g*
Blackspot tuskfish	*Choerodon schoenleinii*	$W=0.0000286246TL^{2.944}$	Fairclough, D. 2003	*mm and g*

Appendix E – The common and scientific names of species in this thesis

Common name	**Scientific name**
Barramundi	*Lates calcarifer*
Western blue devil	*Paraplesiops meleagris*
Fingermark bream	*Lutjanus johnii*
Silver bream	*Rhabdosargus sarba*
Catfish, unidentified	*Arius spp*
Chinaman fish	*Symphorus nematophorus*
Breaksea cod	*Epinephelides armatus*
Chinaman cod	*Epinephelus rivulatus*
Estuary cod	*Epinephelus coioides*
Cod, unidentified	*Epinephelus bilobatus*
Brown mud crab	*Scylla olivacea*
Mud crab, unidentified	*Scylla spp*
Western Australian dhufish	*Glaucosoma hebraicum*
Blue-lined emperor	*Lethrinus laticaudis*
Blue-spotted Emperor	*Lethrinus punctulatus*
Long-nosed emperor	*Lethrinus olivaceus*
Red emperor	*Lutjanus sebae*
Spangled emperor	*Lethrinus nebulosus*
Sweetlip emperor	*Lethrinus miniatus*
Emperor, unidentified	*Lethrinidae*
Western foxfish	*Bodianus frenchii*
Baldchin groper	*Choerodon rubescens*
Gurnards, unidentified	*Peristediidae*
Harlequin fish	*Othos dentex*
Australian herring	*Arripis georgianus*
Rosy jobfish	*Pristipomoides filamentosus*
Knife jaw	*Oplegnathus woodwardi*
Leatherjackets, unidentified	*Monacanthidae*
Narrow-barred spanish mackerel	*Scomberomorus commerson*
Mangrove jack	*Lutjanus argentimaculatus*
Oysters	*Ostreidae*
Moses perch	*Lutjanus russelli*
Pearl perch	*Glaucosoma buergeri*
Queenfishes, unidentified	*Scomberoides spp*
Western rock lobster	*Panulirus cygnus*
White-blotched rankin rockcod	*Epinephelus multinotatus*
Australian salmon	*Arripis truttaceus*
Samson fish	*Seriola hippos*
Robinson's seabream	*Gymnocranius grandoculis*
Crimson seaperch	*Lutjanus erythropterus*
Red seaperch	*Ellerkeldia rubra*

Saddle-tailed Seaperch	*Lutjanus malabaricus*
Stripey seaperch	*Lutjanus carponotatus*
Sergeant baker	*Aulopus purpurissatus*
Gummy shark	*Mustelus antarcticus*
Goldband snapper	*Pristipomoides multidens*
Pink snapper	*Pagrus auratus*
Queen snapper	*Nemadactylus valenciennesi*
Red snapper	*Centroberyx gerrardi*
Yellow-eyed Red Snapper	*Centroberyx australis*
Swallowtail	*Centroberyx lineatus*
Sea sweep	*Scorpis aequipinnis*
Bluenose threadfin salmon	*Eleuthronema tetradactylum*
Trevallies, unidentified	*Caranginae spp*
Giant trevally	*Caranx ignobilis*
Golden trevally	*Gnathanodon speciosus*
Gold-spotted trevally	*Gnathanodon speciosus*
Skipjack trevally	*Pseudocaranx dentex*
Coral trout	*Plectropomus leopardus*
Sand whiting	*Sillaginidae*
King george whiting	*Sillaginodes punctata*
Western wirrah	*Acanthistius serratus*

Appendix F - Semivariograms and models

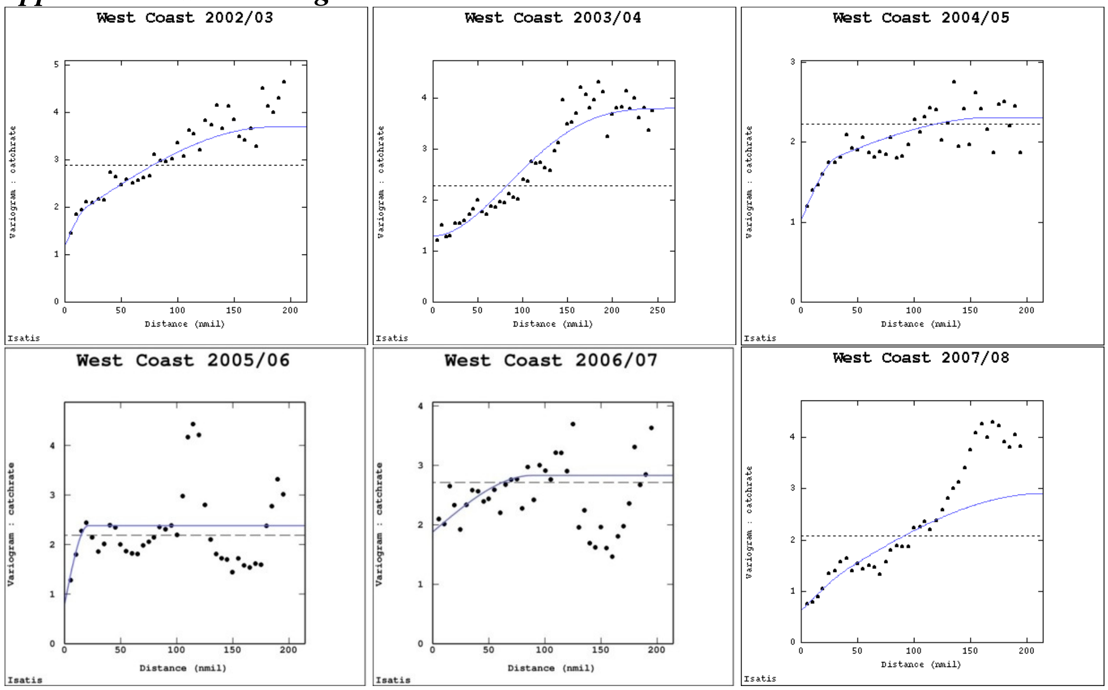

Figure F1: Semivariograms and models for the West Coast bioregion between 2002/03 and 2007/08.

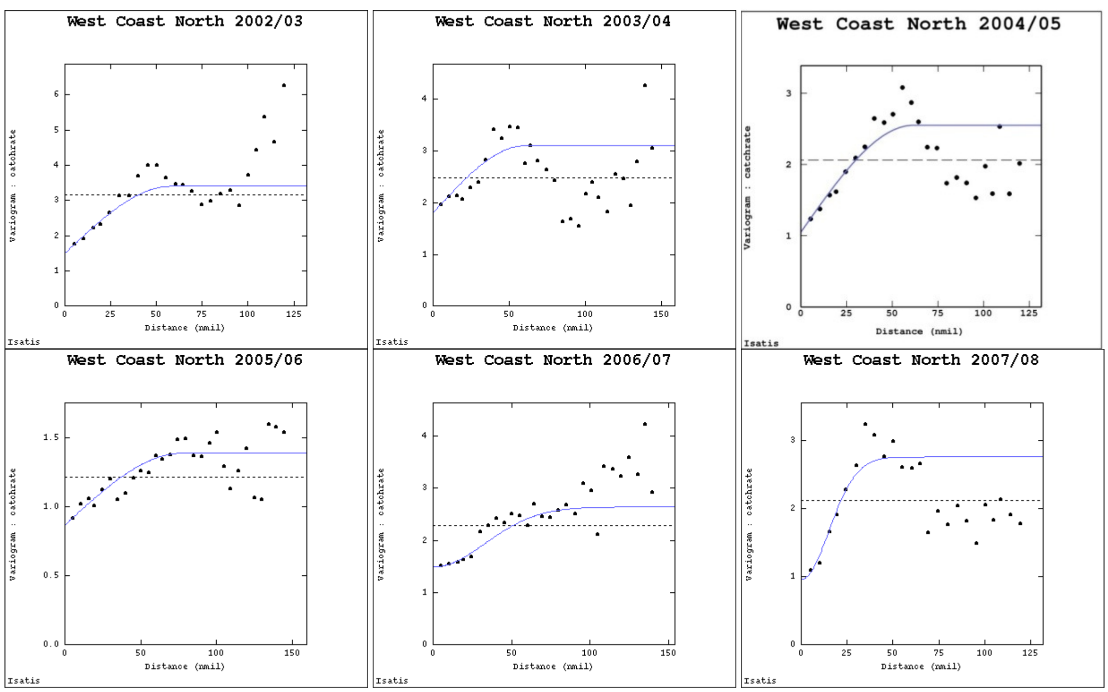

Figure F2: Semivariograms and models for the West Coast bioregion – north between 2002/03 and 2007/08.

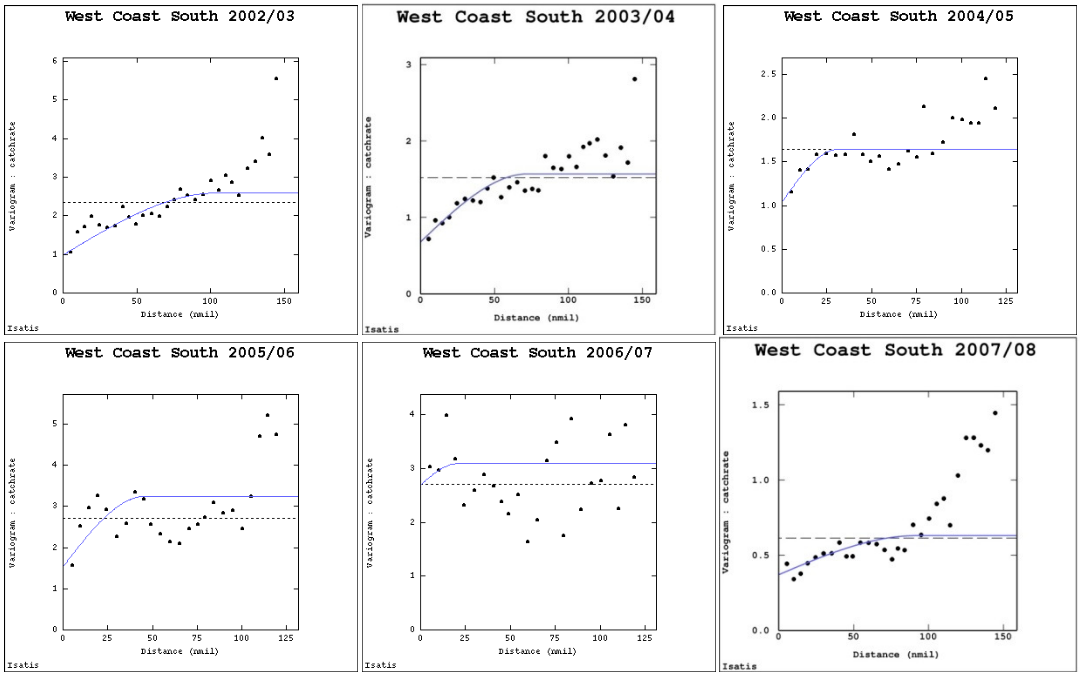

Figure F3: Semivariograms and models for the West Coast bioregion – south between 2002/03 and 2007/08.

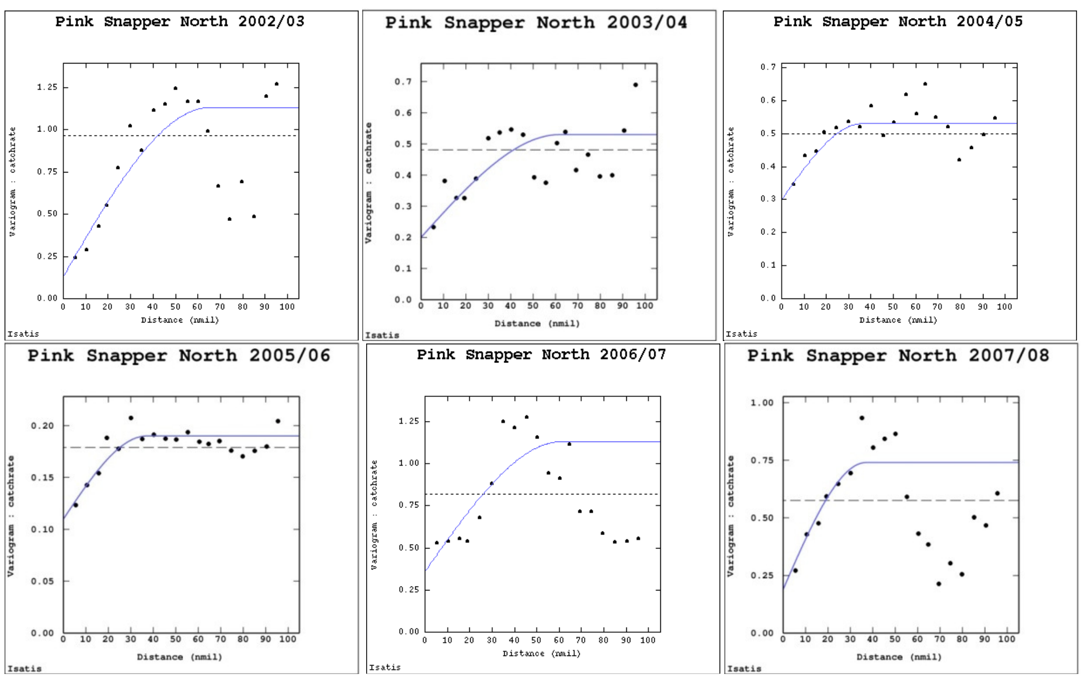

Figure F4: Semivariograms and models for pink snapper – north between 2002/03 and 2007/08.

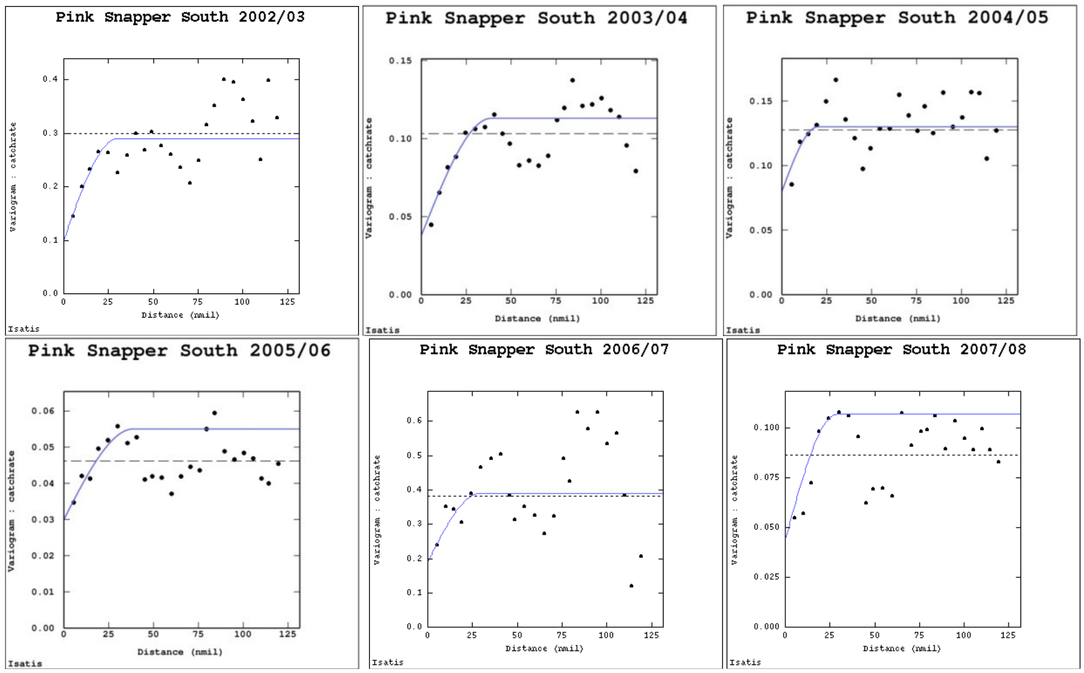

Figure F5: Semivariograms and models for pink snapper – south between 2002/03 and 2007/08.

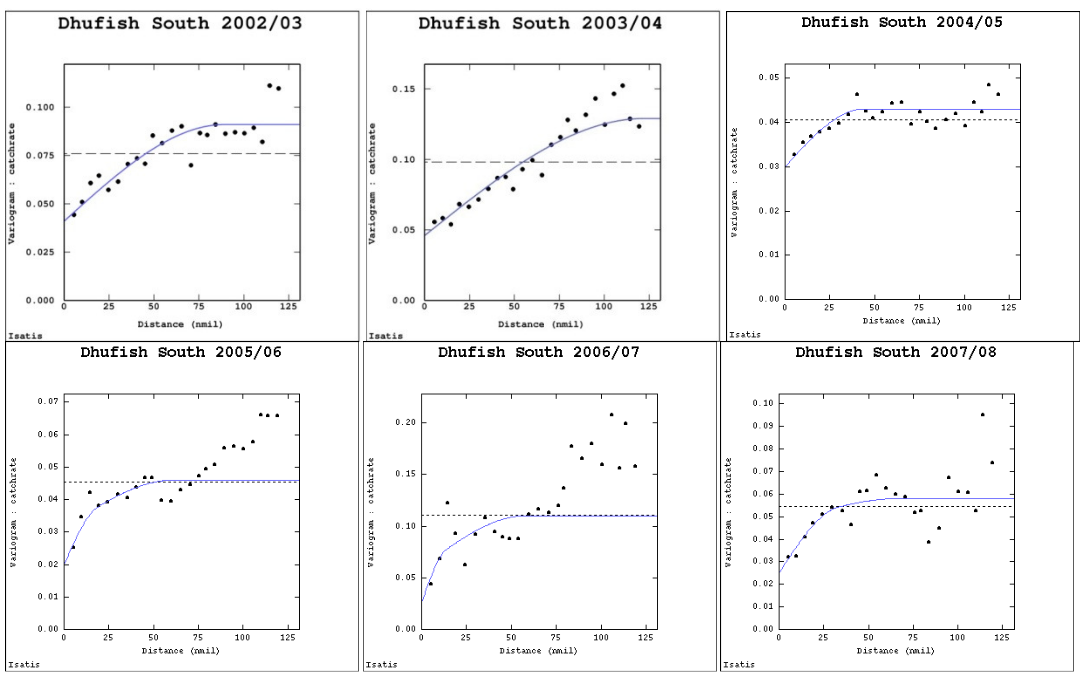

Figure F6: Semivariograms and models for dhufish – south between 2002/03 and 2007/08.

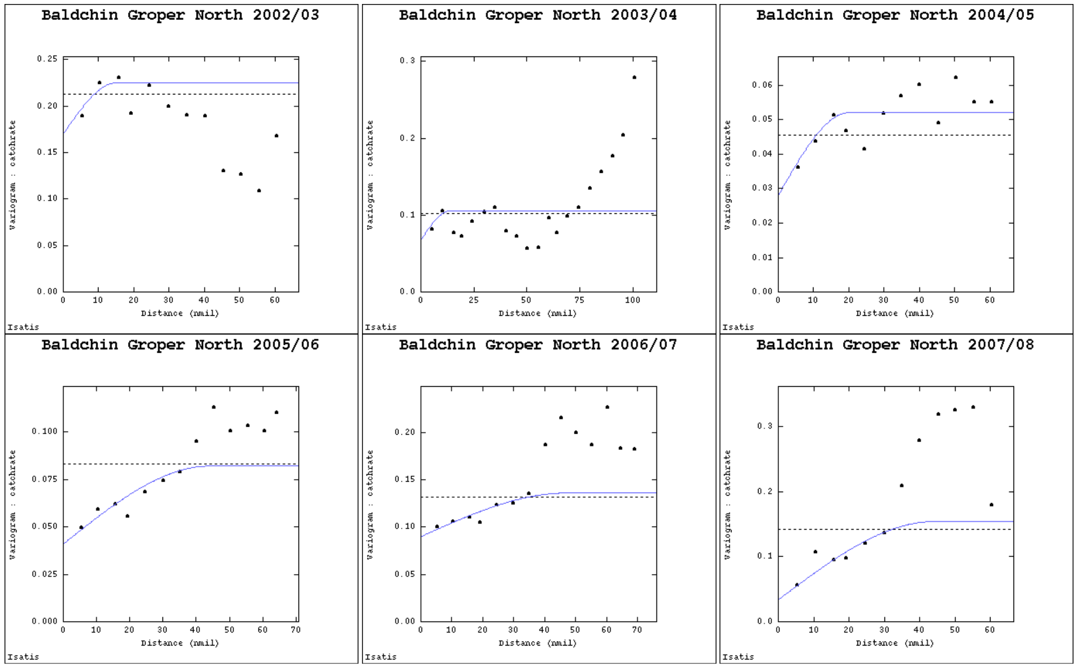

Figure F7: Semivariograms and models for baldchin groper – north between 2002/03 and 2007/08.

Appendix G1 – Social and Economic questionnaire, page 1

Department of Fisheries
Government of Western Australia

ECU EDITH COWAN UNIVERSITY

My name is Carli Johnson and I am a Masters Student at Edith Cowan University. I am asking for your help with a questionnaire that will provide information about social and economic aspects of the Western Australian Charter Industry.

I ask that you please spend 5 minutes answering the following 13 questions based on your independent experience and opinions. There is no personally identifiable information asked in the questionnaire and your answers will be kept confidential. Once completed, please hand your questionnaire back to the operator (skipper/driver).

1. What is your Nationality and postcode/zipcode of your permanent place of residence?
   E.g. Australian, 6000 or British, SW1D 141
   ________________ ☐☐☐☐☐☐☐☐

2. What is your gender?
   ☐Male ☐Female

3. What is your age group (years)?
   ☐17 or younger ☐45 – 54
   ☐18 – 24 ☐55 – 64
   ☐25 – 34 ☐65 and over
   ☐35 – 44

4. What is your annual income group (AUD)?
   ☐$1 – $7,799 ☐$67,600 – $83,199
   ☐$7,800 – $20,799 ☐$83,200 – $103,999
   ☐$20,800 – $41,599 ☐$104,000 or more
   ☐$41,600 – $67,599

5. What is the price range you paid for the charter service today (AUD)?
   ☐$0 – $100 ☐$301 – $400
   ☐$101 – $200 ☐$401 – $500
   ☐$201 – $300 ☐$500+

6. Which of the following best describes how you heard about the charter service you used today?
   ☐Tourist Bureau ☐Internet
   ☐Newspaper/magazine ☐Friends and relatives
   ☐Television ☐Other (specify) ________________
   ☐Radio

Appendix G2 – Social and Economic questionnaire, page 2

7. Did you fish during today's charter service?
   - ☐ Yes ☐ No (move to Q11)

8. If you fished, which of the following best describes your main activity on the charter service today? (**only** tick one)
   - ☐ Fishing with a line ☐ Crabbing
   - ☐ Fishing with a rod and reel ☐ Potting
   - ☐ Spearfishing ☐ Other (specify) ____________________

9. If you were fishing on today's charter service, which of the following best describes your reason for fishing?
   - ☐ Food
   - ☐ Sport (catch and release)
   - ☐ Other (specify) ____________________

10. What fish were you hoping to catch whilst on the charter service today, *e.g. pink snapper, rock lobster*?

    ____

11. Which of the following describes your activities (other than fishing) on the charter service today?
    - ☐ Diving
    - ☐ Snorkelling
    - ☐ Wildlife observation
    - ☐ Sightseeing
    - ☐ Other (specify) ____________________

12. How many times over the past 12 months have you used a charter service in Western Australia?
    - ☐ 1
    - ☐ 2 – 3
    - ☐ 4 – 5
    - ☐ 6 – 8
    - ☐ 9 – 12
    - ☐ 13+

13. How satisfied are you with the experience you received on today's charter service?
    - ☐ Very dissatisfied
    - ☐ Somewhat dissatisfied
    - ☐ Neither satisfied or dissatisfied
    - ☐ Somewhat satisfied
    - ☐ Very satisfied

Thank you for participating in this survey

Appendix G3 – Letter accompanying the questionnaire

To the License Holder

Project Title - The Western Australian Charter Boat Industry: Working towards long-term sustainability

I am writing to ask for your help with a questionnaire that will provide information about social and economic aspects of the Western Australian Charter Boat Industry, which is currently not known.

I have enclosed 10 questionnaires for you to provide to your (clients) participating and using your charter service. I ask that you simply provide the questionnaire to any of your clients at the end of the charter service, collect them after they are completed and place them in the reply paid envelope provided. Remember the questionnaire needs to be completed by your clients, not you. If you only have a small number of clients on the tour, then you can simply use them on the next tour, until all 10 are completed.

I have posted questionnaires to all holders of a Tour Operators (Charter) license issued by the Department of Fisheries (including restricted and aquatic eco-tourism licenses). Your participation is important if I am to obtain reliable information. I want to encourage all license holders to provide the questionnaires to their clients.

The questionnaire data provided by your clients will be kept completely confidential, and only I will have access to individual survey returns – no other organisation will be given access to them. Your name will never be placed on the survey or used in any reports and is completely confidential. The survey has an identification number that allows me to calculate a response rate to the questionnaire only.

The project is supported by Edith Cowan University and the Department of Fisheries and has been approved by the Edith Cowan University Human Ethics Research Committee. If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact: Kim Gifkins, Research Ethics Officer Edith Cowan University, 100 Joondalup Drive JOONDALUP WA, 6027 Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au. Results from this project will be available after it is complete, and some information may be published in scientific papers.

Please use the enclosed reply paid envelope to return the questionnaires ASAP. If you have any questions about the questionnaire or the project, please contact me on 92030145 or my Edith Cowan University supervisor Dr Glenn Hyndes 6304 5798.

Yours sincerely,
Carli Telfer
1st September 2008

Appendix G4 – Reminder letter to submit the questionnaires

To the License Holder

Project Title - The Western Australian Charter Boat Industry: Working towards long-term sustainability

On the 1st September I wrote to you asking for your help with a questionnaire that will provide information about social and economic aspects of the Western Australian Charter Boat Industry. I posted 10 questionnaires for your clients to complete whilst using your charter service.

For those who have called and/or returned the questionnaire I thank you so much for the feedback and support, it is greatly appreciated. If you haven't sent them back yet, can you please do so as soon as possible. It is important I get as many responses as possible to ensure it accurately reflect the industry.

Please note I will be sending another three (3) questionnaire drops for each season over the next year, so your assistance would also be greatly appreciated.

Please use the reply paid envelope to return the questionnaires sent to you. If you have any questions about the questionnaire or the project, please contact me on 92030145 or my Edith Cowan University supervisor Dr Glenn Hyndes 6304 5798.

Yours sincerely,

Carli Telfer
1st October 2008

Appendix H – List of all species charter clients were hoping to catch

Common name
Anything
Baldchin groper
Barramundi
Big fish
Billfish
Black jew
Black marlin
Blackspot tuskfish
Blacktip reef shark
Blowfish
Bluebone
Breaksea cod
Chinaman cod
Cod
Coral cod
Coral trout
Dhufish
Edible fish
Emperors
Estuary cod
Fingermark bream
Giant Trevally
Goldband snapper
Golden trevally
Mackerel
Mahi mahi
Mangrove jack
Marlin
Mud crabs
Mulloway
NW snapper
Perch
Pink snapper
Queenfish
Red emperor
Red snapper
Reef fish
Robinson seabream
Rock lobster
Saddletailed seaperch
Sailfish
Seaperch
Snapper
Spangled emperor

Narrow barred spanish mackerel
Sweetlip
Threadfin salmon
Trevally
Tuna
Tuskfish
Threadfin whiskery salmon