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# Biology and stock status of inshore demersal scalefish indicator species in the Gascoyne Coast Bioregion

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# Contents

## Executive Summary

The Gascoyne Coast Bioregion, which extends from Kalbarri (27°S) northwards to Onslow (114°50'E), includes the iconic Shark Bay and Ningaloo World Heritage areas plus the regional centre of Carnarvon and coastal towns of Denham, Coral Bay and Exmouth. The Gascoyne Bioregion is a transition zone between tropical and temperate waters and supports a diverse range of commercial invertebrate and scalefish fisheries and provides a large variety of recreational fishing opportunities. This report investigates the stock status of the inshore demersal scalefish "suite" of species for the Gascoyne region. These bottom dwelling fish are primarily taken by line fishing in waters of 20-250 m depth by both the commercial and recreational sectors.

The inshore demersal scalefish resource of the Gascoyne Coast Bioregion has been identified, along with the West Coast demersal scalefish resource, as one of the highest priority finfish resources to be brought under the Integrated Fisheries Management (IFM) framework in WA (DoF 2000a). The IFM framework seeks to set total sustainable harvest levels for each stock that allows for ecologically sustainable fishing and then allocate explicit catch shares among the commercial, recreational and indigenous sectors. This report presents assessments of the current status of the key indicator stocks for the inshore demersal scalefish fishery resource of the Gascoyne Coast Bioregion. Any identified risks to sustainability can then be used to assist the setting of a total sustainable harvest level for the entire suite of inshore demersal scalefish species, which is one of the first steps of the IFM process. This is especially important, given the potential for increasing levels of demersal scalefish catches from all sectors in this Bioregion.

Commercial line-fishing for finfish in oceanic waters off Shark Bay dates back to the early 1900s, with vessels sailing northwards from Geraldton and later, from Fremantle, to target pink snapper (*Pagrus auratus*) spawning aggregations in winter. The fishery that is now managed as the Gascoyne Demersal Scalefish Fishery (GDSF, commenced in November 2010) first came under formal management in 1987 with the creation of the Shark Bay Snapper Managed Fishery (SBSF). Since 2001, the commercial fishery for pink snapper has been fully quota-managed, using an explicit Total Allowable Commercial Catch (TACC) for the oceanic stock. GDSF vessels are not permitted to fish in the inner gulfs of Shark Bay. The composition of the catch taken by the GDSF has now expanded to include a range of other demersal scalefish species including goldband snapper (*Pristipomoides multidens*), ruby snapper (*Etelis carbunculus*), redthroat emperor (*Lethrinus miniatus*), various cod species (Serranidae), trevallies (Carangidae), and mulloway (*Argyrosomus japonicus*). No State-licensed commercial vessels, including the GDSF, are permitted to fish in waters of the Gascoyne Bioregion between Point Maud and Tantabiddi Well, which is offshore of the Ningaloo Marine Park.

Shark Bay and Ningaloo are both very popular tourist destinations, especially during the winter months and school holidays. A significant component of this tourism is based on water related activities; a large proportion of which is recreational fishing (Smallwood 2009). Large numbers of recreational vessels plus a limited number of licensed charter vessels fish in these waters both inside and outside Shark Bay, off Carnarvon and around Ningaloo. These vessels target the same suite of demersal scalefish species that are also taken by the GDSF and are broadly managed using a combination of daily bag, possession, trip and size limits coupled with limitations on the use of certain fishing gears. Within the inner gulfs of Shark Bay more complex arrangements apply for the pink snapper stocks including recreational quotas. More fine-scale spatial management arrangements also apply in specific conservation areas (e.g. sanctuary zones) in both the Shark Bay and Ningaloo Marine Parks.

The demersal scalefish species taken by commercial, recreational and charter fishers in the Gascoyne Bioregion includes approximately 70-80 species. Consistent with the Department's Ecosystem Based Fisheries Management (EBFM) (Fletcher *et al.* 2010) and Resource Assessment Frameworks (RAF) (DoF 2011), assessment of the status of the entire Gascoyne demersal scalefish resource is based on the status of three indicator species: four stocks of pink snapper, spangled emperor (*Lethrinus nebulosus*) and goldband snapper. These three species were identified as the best representatives of the inshore demersal scalefish suite in the Gascoyne using a comprehensive risk based process that considers species biological vulnerability (longevity, age at maturity, spawning strategy). Only the more vulnerable species in the suite can be selected and especially those that form a significant component of the catch are most appropriate as indicators to ensure that they can be monitored efficiently.

There are four genetically separate stocks of pink snapper in the Gascoyne region (Oceanic, Freycinet, Denham Sound and Eastern Gulf) (MacDonald 1980; Johnson *et al.* 1986; Whitaker and Johnson 1998; Baudains 1999). There is only a single genetic stock of spangled emperor in the Gascoyne (Johnson *et al.* 1993; Moran *et al.* 1993; Berry *et al.* 2012) and likely to be only one genetic stock for goldband snapper.

The stock assessment methods used to determine the status for the seven indicator stocks were dependent upon the existing biological and fishery information (commercial, recreational and charter sectors). The available information on the biology, catches, and catch rates of each indicator species and stocks, plus changes in the fishing behaviour and methods for each fishery sector were assessed. The availability of suitably long time-series of data has enabled age-structured, integrated models to be developed to assess the status of each of the four separate stocks of pink snapper. The status of each pink snapper stock was assessed against a management target level of spawning biomass ($B$) defined as 40% of the unexploited levels of spawning biomass.

For goldband snapper and spangled emperor the lack of long time series of data meant that their assessments could only be based on the estimation of the current levels of fishing mortality ($F$) and other relevant information using a 'weight-of-evidence' approach (see Wise *et al*. 2007). The ratios of the various estimates of $F$ and natural mortality ($M$) (performance indicators) for goldband snapper and spangled emperor stocks were compared to the standard Target ($F = 2/3M$), Threshold ($F = M$), and Limit ($F = 1.5M$) management reference points that have been adopted by the Department for these types of species.

The oceanic stock of pink snapper was assessed as being in recovery. The spawning biomass was estimated to be at approximately 30% of the unexploited level of spawning biomass (Threshold) in 2008 but it is projected to reach the Target level (40%) by 2014 if catches are maintained around the current level of 300 tonnes year$^{-1}$. Commercial catches are managed to the TACC while the recreational/charter catch on this stock (12%) is currently managed by regulation, using a combination of minimum size, bag and boat/trip limits.

The assessment of the two of snapper stocks located within the inner gulfs of Shark Bay (Eastern Gulf and Denham Sound) were assessed in 2008 to be above the management target (i.e. greater than 40% of the unexploited level of spawning biomass). The Freycinet Estuary stock, however, was at that time close to the Threshold level (i.e. 30% unexploited level of spawning biomass) but recovering, and was projected to reach the management target level (40%) by 2012.

Pink snapper catches in the inner gulfs are managed to conservative TARCs using a combination of size limits, bag limits, spawning closures and, in the Freycinet Estuary, where the most depleted stock resides, by using a relatively novel quota-tag system. In conclusion, the current risks to sustainability based on these assessments have already been factored into the ongoing adaptive management arrangements for the recovery of the four pink snapper stocks within the Gascoyne Coast Bioregion.

For both spangled emperor and goldband snapper a 'weight-of-evidence' approach , which is consistent with the Department's Level 3 assessment were used to complete the first formal assessment of their risk status.

The level of fishing mortality for spangled emperor was assessed for two parts of the Gascoyne region, north and south of Pt Maud (i.e., "North Gascoyne", "South Gascoyne"). This was done because of known differences in biology (Marriott *et al.* 2011a) and historical fishing and management between these two study regions, and because there was a need to obtain specific information about the sustainability of fishing on demersal scalefish in the Ningaloo Marine Park (i.e., part of the inshore demersal scalefish fishery resource, within the North Gascoyne). Spangled emperor are mostly (67% of total catch) taken by recreational fishers, especially in the North Gascoyne.

Estimates of $F$ for spangled emperor in 2007/08 from the North Gascoyne ranged from $0.9M$ to $1.7M$, which all exceeded the Threshold reference level (i.e. $F >> M$). Some of these estimates marginally exceeded the Limit reference level ($F > 1.5M$). The yield- and egg production-per recruit was determined to be minimally impacted at this level of $F$. However, the per-recruit analyses did not account for unknown temporal dynamics of the fish population so results should be treated only as preliminary estimates until sufficient data are available for a more comprehensive analysis. Based on the behavioural attributes and catch history of this species suggests that there is likely to be localised over-fishing of spangled emperor occurring in the North Gascoyne. Given the lack of increase in catch levels over the ten year period since sanctuary zones were first established but an increase in $F$ over this time suggests that in addition to there being no evidence of any spillover benefits to stocks outside of the sanctuary zones in the Ningaloo Marine Park, it is possible that the concentration of fishing effort into a smaller area may have exacerbated local depletion. However, in terms of the breeding stock, the component residing within sanctuary zones (and not assessed) is largely protected from fishing and is likely to assist in buffering the stock against potential recruitment overfishing.

Estimates of $F$ for 2007/08 from the South Gascoyne ranged from ~0 to $0.8M$, which were either below the Target reference level ($F < 2/3M$) or between the Target and Threshold reference levels ($2/3M < F < M$). Based on the behavioural attributes and catch history of this species suggests that the part of the spangled emperor stock in the South Gascoyne is currently (as at 2007/08) being fished at a sustainable rate.

At the Bioregion level, however, there exists one single genetic stock of spangled emperor. If we assume similar abundances of spangled emperor in the North and South Gascoyne, the Bioregion level of $F$ should be approximately mid-way between presented estimates of $F$ for the North and South Gascoyne. In that case, the median of those presented estimates of $F$, which lies between the Target and Threshold reference levels ($2/3M < F < M$), would be an appropriate representation for spangled emperor at the Bioregion level. This would suggest that the spangled emperor breeding stock in 2007/08 was estimated to be at an acceptable level for the Bioregion overall, noting significant reductions in the relative numbers of older (breeding age) spangled emperor in the North Gascoyne, outside of sanctuary zones, due to localised depletions. It is also noteworthy that the component of the breeding stock in the North Gascoyne residing within sanctuary zones of the Ningaloo Marine Park (and not assessed) may contribute towards buffering against potential recruitment overfishing. Although differences in growth were observed between the North and South Gascoyne, the overall inherent biological productivity (indicating vulnerability) for spangled emperor in the Bioregion was Medium. This suggests that, if an appropriate range of catch reduction is selected (i.e., based on estimated levels of $F$) the level of reduction should be refined towards the middle of that range.

The level of fishing mortality for goldband in 2007/08 was estimated to be at an acceptable level being much less than the Target (i.e. $F<2/3\ M$). Based on the decision rules for these stocks, and incorporating the biological attributes of goldband snapper, at catch levels of around 100-120 $\text{year}^{-1}$ for Zones 1-4 (2007/08 level) there would be a negligible risk to sustainability of this stock. As the commercial catch of goldband snapper across the entire Gascoyne increased by around 20% in 2008/09 compared with the previous year (from ~121 tonnes to ~144 tonnes, Jackson *et al.* 2010a) the risk profile for this species has possibly increased but not to levels that should generate management concern. However, given that the targeting of goldband snapper has only occurred in recent years, the flow through of these catches to the age structure may not yet be complete. Therefore, ongoing monitoring based on age structured sampling allowing Level 3 or higher stock assessments needs to be completed to confirm this low risk profile. In addition, the collection of data to use for developing a suitable index of abundance time series (e.g., from high resolution commercial catch rate data), and biological data to refine biological parameter estimates would assist our understanding of the Gascoyne stock of goldband snapper.

## Summary

**Status**

***Stock level***

| | |
|---|---|
| Pink snapper | |
| Oceanic | Recovering |
| Freycinet | Recovering |
| Denham Sound | Adequate |
| Eastern Gulf | Adequate |
| Goldband snapper | Adequate |
| Spangled emperor | Adequate |

***Fishing Level***

| | |
|---|---|
| Pink snapper (all Stocks) | Acceptable |
| Goldband snapper | Acceptable |
| Spangled emperor | |
| North Gascoyne | Unacceptable |
| South Gascoyne | Acceptable |

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# 1.0 Introduction

## 1.1 Background

To manage the cumulative impacts of fishing and other pressures including population growth, increased coastal development, and meet the broader requirements of Ecological Sustainable Development (DoF 2002) and Ecosystem Based Fisheries Management (EBFM; Fletcher *et al.* 2010), an integrated fisheries management (IFM) framework was adopted by the Department of Fisheries in the early 2000s (DoF 2000a). This approach seeks to set total sustainable harvest levels for each major fishery resource (stock or suite) within a region that allows for an ecologically sustainable level of fishing and to allocate explicit shares of this level among the commercial, recreational and indigenous sectors. Prior to the IFM process commencing, information on the current status and risks to sustainability of the fishery resource is required by fishery managers, to set sustainable harvest levels.

To facilitate adoption of IFM the Department of Fisheries has divided its extensive marine jurisdiction into four Bioregions based on species compositions and ecosystem structure. The West Coast and Gascoyne Coast demersal scalefish were identified as the highest priority finfish resources to be brought under the IFM-framework. This includes those finfish species whose adult individuals, particularly the spawning stock, reside in or proximal to benthic habitats in waters greater than 20 m depth and are generally a major target of line based fishing.

The completion of IFM for demersal scalefish in each of the four marine Bioregions presents a significant challenge given that there are always multiple target species in this suite with multiple fishing sectors targeting these stocks which generates a high level of community interest in the outcomes (Lenanton *et al*. 2006). Sector allocation of these demersal scalefish resources in the West Coast Bioregion has recently been addressed through the release of a Draft Allocation Report prepared by the Integrated Fisheries Allocation Advisory Committee (IFAAC) (DoF, 2010b): This followed the implementation of revised fisheries management arrangements for the recreational and commercial sectors (DoF, 2010a) which were based upon the stock assessment advice generated by Wise *et al*. (2007) and Lenanton *et al.* (2009a & b).

This report outlines the stock assessment information for the demersal scalefish resources of the Gascoyne Coast Bioregion. This bioregion extends for approximately 1,000 km between Kalbarri and Onslow, from north of 27°S to 114°50'E, and includes the iconic regions of Shark Bay and Ningaloo World Heritage Areas plus the regional centre of Carnarvon and the coastal towns of Denham, Coral Bay and Exmouth (Figure 1.1). This marine bioregion represents a major transition between the tropical and temperate zones of the Western Australian coast and has a diverse set of fish species. Full details of the demersal scalefish resource within the Gascoyne are listed in Appendix 1 which was compiled from records of the landed catches reported by commercial, recreational and charter fishers in the Gascoyne, and represents those demersal scalefish species directly impacted by fishing.

The need to address IFM issues for demersal scalefish resources has previously been identified (DoF, 2000c; Rogers and Curnow 2002; Toohey 2002). Given the social and economic value of Gascoyne demersal scalefish to commercial (DoF, 2005; 2006), recreational (DoF, 1998, 2000b; Curnow and Harrison 2001), indigenous fishing (Franklyn 2003) and to the tourism industry (Shaw 2000) in the Bioregion, this fishery resource has been given high priority.

This report presents assessments of the current status of the inshore demersal scalefish resources in the Gascoyne Coast Bioregion. These assessments should generate the scientific information necessary to enable advice to be provided to fisheries managers, who, in consultation with stakeholders and the general public, can establish sustainable harvest levels for the Gascoyne Inshore Demersal Scalefish resource. IFM allocation strategies may then be implemented for the ongoing ecologically sustainable and equitable use of the demersal scalefish resource in the Gascoyne.

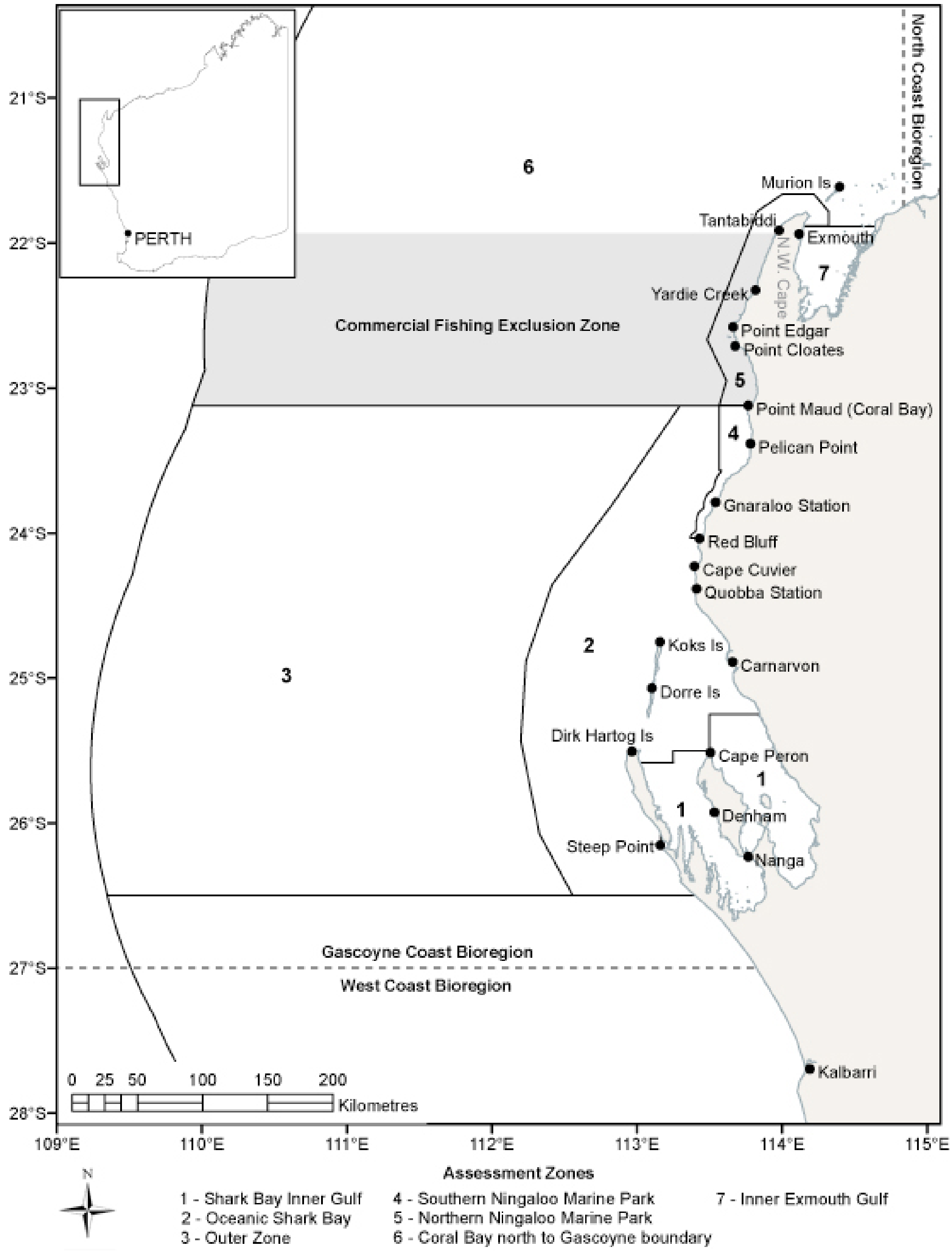



**Figure 1.1.** Gascoyne Coast Bioregion showing the main populations centres and the assessment zones* used in this report.

* Note: the term 'zone' is used in this report with reference to stock assessment purposes and does not relate to management zones. See Section 4.4 for an explanation of assessment zone boundaries.

## 1.2 Indicator species approach

Completing stock assessments for use in the sustainable management of multi-species, multi-sectoral fisheries such as the Gascoyne demersal scalefish resource presents many challenges in both scale and complexity. To address this issue, the Department has adopted the use of a risk based, EBFM process to better manage resources at a whole of region level (Fletcher *et al*. 2010) This involves using the status of one or more indicator species as being indicative of the status of an entire suite (DoF 2011). Where multiple indicator species are in each suite, a precautionary management approach is applied whereby the species with the poorest status determines the overall status of the entire suite. This approach was initially applied to the assessment of demersal scalefish in the West Coast Bioregion by adopting a 'weight-of-evidence' approach to a limited number of indicator species (Wise *et al.* 2007).

The benefits of assessing and managing stocks based on this indicator species approach are twofold: (i) if resources are limited they can be prioritised to allow more frequent assessments for those indicator stocks in order to determine the status of the entire suite/resource and (ii) monitoring and management of fishing on the species that comprise the suite of demersal scalefish stocks is simplified.

Indicator species for the inshore demersal suite (20-250 m) and offshore suite (>250 m) were identified using the risk-based approach outlined in the Department's Resource Assessment Framework (DoF 2011). This approach is based on three criteria including the vulnerability of the species/stock to fishing; their relative contribution to the catches of fishing sectors and importance to support current and future management needs (Lenanton *et al.* 2006, DoF 2011). Through this risk-based assessment process, pink snapper (*Pagrus auratus*), goldband snapper (*Pristipomoides multidens*), and spangled emperor (*Lethrinus nebulosus*) were chosen as the key indicator species for the inshore suite of demersal scalefish of the Gascoyne Coast Bioregion (Appendix 1). Although Spanish mackerel (*Scomberomorus commerson*) is an important component of recreational and commercial catches in the Gascoyne, it was not selected as an indicator species for assessing inshore demersal scalefish stocks as the species is part of the pelagic suite in the Bioregion.

## 1.3 Need

Commercial fishing for pink snapper (oceanic stock, see 5.1.1), which is one of the Gascoyne inshore demersal indicator species, has been under formal management since at least the 1980s. In recent years, several factors have contributed to increased commercial catches of other demersal scalefish in the Gascoyne, including increased effort in deeper waters (>200 m) and increased efficiency due to technological advances (fishing gear, fish finding aids, improved vessel capabilities). This trend was particularly apparent for goldband snapper, where catches rose from low levels to very high levels over a short period (2000-2005, Jackson *et al.* 2010a).

Participation in recreational fishing has also increased, along with an increase in the number of residents living within the region. Improved infrastructure (e.g. sealed roads) has led to increasing levels of domestic and international tourism (Smallwood 2009). Enhanced access to coastal waters via new boat ramps (e.g. Bundegi, Coral Bay) and camping sites/facilities (Gnaraloo) and the sustained popularity of recreational fishing (through increased disposable income of residents employed in developing mineral and petroleum industries) also contribute to pressure on local fish stocks. This trend of increasing levels of recreational fishing effort and catches is also in part related to the recent increased levels of regulation and constraint on recreational fishing in the West Coast Bioregion.

To enable the implementation of IFM for demersal scalefish in the Gascoyne Coast Bioregion, there is a need to gain a better understanding of the biology of the key target species as indicators of the suite of inshore demersal scalefish species, determine the current status of the inshore demersal scalefish resource and assess associated risks to ongoing sustainability. A reliable estimate of current status of the demersal scalefish resource is required to ensure that subsequent management strategies are appropriate for ensuring future levels of total catch by all sectors are sustainable. This is especially important, in light of the abovementioned current pressures on inshore demersal scalefish fisheries in the Gascoyne.

## 1.4 Objectives

The main objectives of this study were to:

1. Characterise the major fisheries exploiting the demersal scalefish resources in the Gascoyne Coast Bioregion

2. Investigate the population biology of spangled emperor to fill existing knowledge gaps required for stock assessment of this indicator species.

3. Obtain and assess representative catch-at-age distributions for Level 3 assessments, consistent with a 'weight-of-evidence' approach (Wise et al. 2007) for goldband snapper and spangled emperor stocks in the Gascoyne Coast Bioregion.

4. Undertake stock assessments of key indicator species and thus assess the status of the inshore demersal suite, to provide advice on the stock status and risks to sustainability, for the management of demersal scalefish resources and fisheries in the Gascoyne Coast Bioregion, within an IFM framework.

The stock assessment approaches that could be used to determine the status of the three indicator species were dependent upon the biological and fishery information (commercial, recreational and charter sectors) that were available for each species. Accordingly, all available information on the biology, catches, and catch rates of each indicator species, and of the effort characteristics of each sector, are presented and summarised in this report. Stock assessments that are based on this information are then reported in context of implications for future IFM of the inshore demersal scalefish resource of the Gascoyne Coast Bioregion.

## 2.0 The Gascoyne Marine Environment

The comprehensive Fisheries Environmental Management Review of the Gascoyne Region (Shaw 2000) provided a thorough account of environmental and socio-economic settings for fisheries management in the Bioregion, including an account of the history and a description of each of the fisheries within each sector, together with an account of the environmental impacts of fishing.

The coastline varies throughout the Bioregion. Fringing coral reefs, some of which are adjacent to high cliffs, dominate the northerly exposed half of the mainland coast. The protected waters of Shark Bay dominate the southern half of the bioregion, where the exposed high-energy marine coast is composed almost entirely of high cliffs, with low relief sandy shorelines and mangroves dominating within Shark Bay. The northern area of the Bioregion (Ningaloo/Exmouth area) is seasonally influenced by tropical cyclones, while the southern area (Shark Bay) rarely experiences cyclones, but is affected by the more intense southerly winter frontal systems, and at times by significant river outflows, primarily from the Gascoyne and to lesser extent Wooramel River. The marine environment represents a transition from a tropical coral reef environment in the north, to a temperate seagrass dominated environment in inner Shark Bay to the south. The waters of the Gascoyne are inhabited by a diverse range of scalefish species distributed within and across different demersal habitats.

# 3.0 The Gascoyne Fishery and Management Arrangements

## 3.1 Spatial management and jurisdictions

A number of significant marine conservation and protected areas have been established in the Gascoyne Coast Bioregion. In the north, the Ningaloo Marine Park was gazetted under the CALM Act, 1984 in April 1987 and recently became part of the Ningaloo Coast World Heritage Area on 24 June 2011. In 1990, the Shark Bay Marine Park was gazetted and in the following year, the Shark Bay World Heritage Property was inscribed on the World Heritage List (1991). During the same year, the first recreational sanctuary zones were created within the Ningaloo Marine Park. In 2005, the southern boundary of Ningaloo Marine Park was extended from Amherst Point to Red Bluff and further re-zoning took place within the Park.

A commercial fishing closure between Point Maud and Tantabiddi Well was implemented in state waters in the early 1970s, and administered under a license condition (16) that prohibited engagement in State-managed commercial fishing in the area (DoF. 2005). Following the Offshore Constitutional Settlement (OCS) in 1995, state responsibility for the management of some of the fishery resources was allocated to Western Australia out to 200 nautical miles (the outer boundary of the Economic Economic Zone [EEZ]).

## 3.2 Commercial

Historically, pink snapper (oceanic stock), was the primary demersal scalefish target species in the Gascoyne Coast Bioregion. Commercial snapper fishing commenced in waters off Shark Bay around 1908 (Shaw 2000). The modern-day commercial fishery commenced after World War II, and was well established by the 1950s (Shaw 2000). The Shark Bay Snapper Fishery (SBSF) came under formal management in 1987, with 1988 the first full year of seasonal quota-based management. A revised quota management system was introduced in 1994. In 2001, the fishery became a fully quota (i.e., pink snapper catch only) managed fishery on a year-round basis. Further management changes included prohibition firstly on line fishing from prawn trawlers in Shark Bay (2000), and subsequently, on non-quota commercial line fishing in waters of the SBSF (2004).

As at 2007 (the focal assessment year for this report, see Section 4.4), commercial line fishing was almost entirely undertaken in the waters off Shark Bay (mainly Zone 2; Fig 1.1) by SBSF licensed vessels. These vessels used mechanised handlines* and, in addition to pink snapper, caught a range of other species including goldband snapper, red emperor (*Lutjanus sebae*), emperors (Lethrinidae, includes spangled emperor and sweetlip, *L. miniatus*), cods (Serranidae), ruby snapper (*Etelis carbunculus*), pearl perch (*Glaucosoma burgeri*), mulloway (*Argyrosomus japonicus*) and trevallies (Carangidae). Commercial 'open-access' wetline vessels† (without SBSF-quota) operated in waters outside of the SBSF management zone (from 23°34'S to 26°30'S) and caught a similar variety of species.

On 1 November 2010 the Gascoyne Demersal Scalefish Fishery (GDSF) came into operation and replaced the SBSF. The GDSF encompasses a larger spatial area than the former SBSF, with the northern boundary being shifted from 23°34'S northwards to Point Maud (23°07'S) (coincides with Zone 2; Fig 1.1).

* A hydraulic or electric gunwhale-mounted handline reel

† Vessels operating under a general permit for commercial fishing in state waters

In the extreme northern area of the Bioregion many of these species are also targeted by the Pilbara Line Fishery. Small catches of these species are also taken as by-product in several of the other state-based commercial fisheries that operate within the Gascoyne Bioregion (e,g, Shark Bay Beach Seine and Mesh Net Fishery).

Pink snapper and other scalefish species are a minor bycatch of the Shark Bay Prawn Fishery and to a lesser extent, the Shark Bay Scallop Fishery (Sporer *et al.* 2009). Very small catches of larger individuals of pink snapper and mulloway taken by trawling are retained. The effect of trawling in the more northerly waters of Shark Bay on various species that occur as non-retained bycatch was formally assessed in an extensive survey conducted between 2002 and 2004 (Kangas *et al.* 2007).

In the inner gulfs, a formal study determined that trawl fisheries in Denham Sound constituted an additional source of fishing mortality of juvenile pink snapper in that area (Moran and Kangas 2003). Historically, small quantities of sub-adult and adult pink snapper have been retained as byproduct in the inner gulfs by the Shark Bay Beach Seine and Mesh Net Fishery.

A quantity of large individuals of the oceanic pink snapper stock, and other demersal scalefish are also retained as byproduct by the Commonwealth managed Western Deepwater Trawl Fishery that operates in waters of the Gascoyne in Commonwealth waters deeper that 200 m (AFMA 2006).

The key inshore demersal indicator species in the Gascoyne Coast Bioregion that are the focal species of this report are pink snapper, spangled emperor and goldband snapper. For these species, the relative magnitude of the catch varies among the sectors, due to the different targeting practices and catch compositions (Table 3.1). More detailed descriptions of historical levels of catch and effort for the commercial, recreational and charter sectors are provided in Section 6 with a brief summary of trends in catch levels as follows.

**Table 3.1.** Indicator species catch for assessment year 2007: Gascoyne Coast Bioregion. See Section 6 for further details.

| | | Recreational | Charter | Commercial | Total |
|---|---|---|---|---|---|
| **Pink snapper** | | | | | |
| | Catch (T) | 31 | 21 | 302 | 354 |
| | Catch (%) | **9%** | **6%** | **85%** | |
| **Spangled emperor** | | | | | |
| | Catch (T) | 30 | 8 | 7 | 45 |
| | Catch (%) | **67%** | **18%** | **15%** | |
| **Goldband snapper** | | | | | |
| | Catch (T) | Not available | 5 | 119 | >124 |
| | Catch (%) | | | | |

The commercial pink snapper catch increased from 423 t in 1975/76 to an all-time peak of 1287 t in 1984/85 before stabilising between approximately 400-600 t from 1987/88 to 2001/02, and following a series of quota-reductions, declining to 302 t by 2007/08. The recreational pink snapper catch (estimated) decreased between 1998/99 and 2007/08 with most of the catch taken in the inner gulfs of Shark Bay (i.e. Zone 1) during the early period compared with mostly from oceanic waters (i.e., Zone 2) in the more recent period.

Charter catches have remained at around the same level (approximately 20 t) since 2001. The current status of the pink snapper oceanic stock is that the spawning biomass is rebuilding and fishing is now at an acceptable level (Jackson *et al.* 2010a). Spawning biomass of pink snapper in the Easter Gulf and Denham Sound is adequate and in the Freycinet Estuary is recovering. Fishing levels for all three inner gulf stocks is at an acceptable level (Jackson and Norriss 2010).

Although the current commercial catch of spangled emperor is relatively small compared to its recreational catch, the commercial catch has historically been much higher. Annual catches of more than 100 t of spangled emperor were landed from the mid-1980s to the early 1990s (peaking at 215 t in 1988/89), which coincided largely with an increase in trap and line fishing north of the SBSF at the time (Moran *et al.* 1993; Section 6). This species has long primarily been a non-target by-product species of the SBSF, however, and a recent reduction in commercial catches of this species reflects a shift in targeting towards other, more high-valued species, such as goldband snapper, when not targeting pink snapper. The recreational catch was higher in 1998/99 than it was in 2007/08 and the charter catch was higher in 2002/03 before declining to the 2007/08 level. The stock level of spangled emperor is adequate whilst the fishing level in the North Gascoyne is unacceptable and the fishing level in the South Gascoyne is acceptable (Jackson *et al.* 2010a).

The historical commercial catch of goldband snapper was relatively low (< 50 t) prior to 2000/01, then increased rapidly to peak at relatively high levels (around 300 t) from 2002/03 to 2004/05, as a consequence of increased targeting of this species in deeper waters. Commercial catches then dropped in 2005/06 to 126 t and stayed at a similar level to 2007/08. Catches by charter and recreational sectors have been relatively low in comparison. Charter catches increased from 0.3 t in 2002/03 to the 2007/08 level and the recreational catch was higher in 2007/08 than it was in 1998/99 (estimated numbers of fish retained). The stock level of goldband snapper is adequate and the fishing level is acceptable (Jackson *et al.* 2010a).

## 3.3 Recreational

A detailed description of recreational fishing in the Gascoyne can be found in Shaw (2000). Briefly, recreational fishing and tourism in the Gascoyne is relatively seasonal with the warm, dry winter climate making the area a popular winter recreational fishing destination for southern-based recreational fishers, especially from the Perth metropolitan region. Recreational fishing activities occur throughout most of the Bioregion, particularly in the Ningaloo Marine Park and Shark Bay and include beach and cliff fishing (e.g. Steep Point, Quobba station, Ningaloo Reef), embayment and shallow-water boat angling (e.g. Shark Bay, Exmouth Gulf and Ningaloo Reef lagoons), offshore boat angling for demersal and larger pelagic species, and some spearfishing. Recreational fishing is predominantly for tropical species such as spangled emperor, red emperor, coral trout (*Plectropomus leopardus*) and narrow-barred Spanish mackerel, but temperate species, such as pink snapper, mulloway, tailor (*Pomatomus saltatrix*) and yellowfin whiting (*Sillago schomburgkii*) are also targeted, particularly within the inner gulfs of Shark Bay (Zones 1, 2; Fig 1.1).

Recreational fishing in the Gascoyne has been managed via a bioregional specific management strategy since 2003 (Curnow and Harrison 2001). This strategy consists of a set of bag, possession and size limits, permitted gear types, and seasonal and area closures implemented under the Fish Resources Management Act 1994 (DoF. 2001, 2010c). With the exception of pink snapper in Shark Bay's inner gulfs, these arrangements are largely based on social values and are not intended to manage the recreational catch to a target level. Specific strategies have been implemented in Shark Bay's inner gulf to manage to recreational take of pink snapper to an explicit target catch level. This includes a novel management quota-tag based system for fishing for pink snapper in the Freycinet Estuary (Mitchell *et al.* 2008). All recreational fishing activities, including those of the charter sector, are subject to the closures associated with the Ningaloo and Shark Bay Marine Park Sanctuary Areas, Nature Reserves, and Conservation areas.

Most recently, a state-wide recreational boat-fishing license was introduced in March 2010.

## 3.4 Charter

In order to ensure ongoing sustainability of the industry and the fish resources it exploits, formal management arrangements were introduced for the charter sector in 2001, including a 'cap' on the total number of operators state-wide (DoF. 2000c; Johnson 2008). Licensed operators that are engaged in extractive fishing (i.e. fishing tour operators) are required to submit trip-by-trip catch and effort records. Otherwise, charter fishing is subjected to the same regulations as private recreational fishers. Key demersal species targeted in the Gascoyne Coast Bioregion by charter operators include pink snapper, sweetlip emperor and spangled emperor. The majority of the charter catch is taken over the autumn/winter period (April to August).

## 3.5 Indigenous

There are relatively large aboriginal communities within the Gascoyne Coast Bioregion, and fishing is a popular activity (Shaw 2000). People of aboriginal descent do not need a recreational fishing license if fishing using traditional methods. However they are required to fish within the recreational fishing rules. As such, their catches would be recorded as part of regional recreational surveys. To date, the only survey designed to document the indigenous catch was the national Recreational and Indigenous Survey carried out in 2000/01 (Henry and Lyle 2003). While this survey did not present data separately for regional Western Australia, what is clear from this report is that the vast majority of the indigenous catch is from inland and coastal waterways. Thus this sector is unlikely to retain many inshore demersal scalefish in this Bioregion.

# 4.0 General methods

## 4.1 Sample collection

### 4.1.1 Fishery-dependent methods

Samples of pink snapper (oceanic stock, see 5.1.1 for details) and goldband snapper were obtained from commercial catches landed by SBSF licensed vessels. These vessels use mechanised handlines and droplines in water depths of 30-300 m to catch a range of demersal scalefish species (Jackson *et al*. 2010a). Biological sampling of SBSF catches dates back to the early 1980s (Moran *et al.* 2005). More comprehensive routine sampling commenced in 2004 following a major reduction in the oceanic pink snapper Total Allowable Commercial Catch (TACC) and in order to meet *Environment Protection and Biodiversity Conservation Act 1999* export-exemption related requirements (see below).

Fishery-dependent samples of pink snapper (oceanic stock) collected between 1992-2008, and of goldband snapper collected between 2004-2008, were used in the stock assessments reported here (Tables 5.1.1, 5.3.1.). No samples of either species were obtained from recreational or charter catches as part of this study. Catch sampling of pink snapper and goldband snapper from oceanic waters was focussed on the commercial sector, which takes approximately 80-90% of the total catch of these two species.

During the 1980s and 1990s, commercial catch sampling of oceanic pink snapper involved the measurement of large numbers of fish and sub-sampling to collect otoliths at fish processors in Carnarvon, mostly during the peak season (May-August). From 2004 onwards, a more comprehensive year-round sampling design was implemented. Craine *et al.* (2009) had determined that the target sample size for age structure monitoring was 300-500 specimens (otoliths) per stock per year. Based on this, and information on the seasonality of the commercial oceanic pink snapper fishery, a stratified sampling design was implemented with larger numbers of samples collected during the months of highest catch with an overall target of ca. 25-30 otoliths from 20 separate catches per year/season (total 500-600 otoliths).

In the inner gulfs of Shark Bay, samples of pink snapper from the separate Eastern Gulf, Denham Sound, Freycinet Estuary stocks (see 5.1.1) were obtained from recreational catches in the Freycinet Estuary only (Table 5.1.1).

Samples of spangled emperor used in the stocks' assessments reported here were obtained from recreational, charter and commercial catches between June 2006 and June 2008 (Table 5.2.1.). The majority of specimens from the recreational catch in 2007 were donated as fish frames following interviews undertaken for the DoFWA Recreational Fishing Survey, 1 April 2007 to 31 March 2008 ('RFS': See Section 6.1.2.2 for details). Collection points for frames donated during RFS interviews at boat ramps ('RFS ramp') or at other popular coastal fishing locations ('RFS roving') were located at Steep Point, Carnarvon, Quobba Station, Gnaraloo Station, Coral Bay and Exmouth (Fig. 1.1). Since the RFS sampling design was stratified spatially (boat ramp/shore fishing location) and temporally (month) in relation to recreational effort (Sumner *et al.* 2002) it was assumed that catches of spangled emperor were also directly proportional to this fishing effort in time and space. Accordingly, the RFS ramp and RFS roving samples of spangled emperor were assumed to be representative of the recreational catches in the Gascoyne.

Spangled emperor were also collected from recreational fishers as fish frames donated at weigh-in evenings during popular fishing tournaments (Gamex, Denham Fishing Fiesta, Carnarfin in 2007 and 2008) or donated at collection points at times other than during RFS interviews

('Donated/other'; Table 5.2.1.). Where possible, information was provided by fishers on the date, location (within 'blocks' delineated by five minute grids of latitude and longitude), depth of capture and the location of where catches were landed. Plastic bags and waterproof data labels were made available to recreational fishers at the collection points, which were often proximal to popular fish filleting areas, and signs were erected to provide instructions to recreational fishers on how to record data on waterproof labels and submit filleted frames for collection. Incentives (e.g. stubby holders, t-shirts, tackle shop vouchers) were offered as rewards for donating fish frames. Collections of spangled emperor from the landed catches of charter and commercial fishers were also undertaken. Relatively few commercial specimens were collected from the SBSF because spangled emperor is currently a commercial byproduct species and landed in relatively small amounts infrequently throughout the year (Table 5.2.1.).

The sampling targets determined by Craine *et al.* (2009) of 300-500 fish per stock per year were also used for spangled emperor and goldband snapper in this study.

### 4.1.2 Fishery-independent methods

No fishery-independent samples of pink snapper (oceanic stock) were collected as part of this study, as the fishery-dependent sampling methods were more efficient and cost-effective for obtaining representative samples of the catches and describing biological parameters of the stock. Fishery-independent samples from the inner gulfs of Shark Bay (Eastern Gulf, Denham Sound, Freycinet Estuary, see 5.1.1) were obtained between 1998-2007 by DoFWA research staff assisted by volunteer recreational fishers, using rod and line fishing. Fishery-independent methods were employed with inner gulf pink snapper because since 1996, 90-100% of the catch has been taken by recreational vessels and opportunistic sampling of recreational catches landed at the public boat ramps was not cost-effective.

Fishery-independent samples of goldband snapper were collected by DoFWA research staff on board the *RV Naturaliste* using longlines and baited traps, in waters of depths of ~40-170 m off Shark Bay, in 2005 and 2007 (see Table 5.3.1). These specimens were used primarily to supplement those collected by the more inexpensive fishery dependent sampling for estimating biological parameter estimates for the goldband snapper stock. Fishery-independent sampling was useful for sampling the stock without being constrained by the fishing patterns of commercial fishers, although the fishery-dependent sampling was considered to provide a better representation of stock demographics spatially and temporally.

Fishery-independent (Research) samples of spangled emperor smaller than the minimum legal size limit (MLL: 410 mm total length, TL) were collected by deploying fine-meshed baited traps in shallow (2 to 5 m) lagoonal habitats of the Ningaloo Reef and by shore-based line fishing with small baited hooks in November 2006 and April 2007 (see Table 5.2.1). Targeted collections of small fish were made by fine-mesh trapping in shallow waters of Shark Bay in March 2008. Targeted collections of adult fish during the peak spawning period (between new moon of October 2007 and the full moon of November 2007) were undertaken by research line fishing in locations of the Ningaloo Reef that were suspected to be spawning aggregation sites. Thus, the more expensive fishery-independent sampling was done to address specific research questions concerning the estimation of biological parameters for the exploited stocks, whereas fishery-dependent sampling was done primarily to obtain representative samples of the catches (and stocks) for stock assessment.

## 4.2 Sample processing

All fish were measured (total length TL, and/or fork length FL, to nearest 1 mm) and weighed were possible (whole wet weight, nearest 1 g).

### 4.2.1 Otoliths

For all three demersal indicator species, both sagittal otoliths were extracted, cleaned, dried, and stored in labelled paper envelopes. Sagittal otoliths were subsequently processed to produce high quality transverse sections (0.3-0.5 mm thick) following the methods described in Jenke (2002)**,** Lewis and Mackie (2002) and Newman and Dunk (2003). Sections were examined microscopically (20-40 x magnification) under reflected light against a black background. Opaque zones were counted along an axis on the ventral margin of the sulcus acusticus for pink snapper (completed opaque zones only) and goldband snapper and along the dorsal margin of the sulcus acusticus for spangled emperor. A readability score and categorisation of the otolith outer margin (translucent or opaque) were also recorded.

To ensure that opaque zones in otoliths were counted for estimating fish ages consistently among different age readers among years, the following quality control procedures were adopted for each species:

***Pink snapper: Inner gulfs***

All otolith sections were read twice, and in cases where the opaque zone counts differed, on a third occasion, by a single experienced reader (GJ). Counts were included in the subsequent analyses only in cases where there was agreement between any two or more readings. Precision in counts between the 1$^{st}$ and 2$^{nd}$ readings was estimated using an index of average percent error (IAPE, Beamish and Fournier 1981). A second experienced reader (JN) independently read a random sub-sample of sections from a representative size range of fish to investigate between-reader bias using an age-bias plot (Campana *et al*. 1995). Further details of ageing protocols for pink snapper from the inner gulfs are given in Jackson (2007).

***Pink snapper: Oceanic stock***

The sections of otoliths that were collected prior to 2006 were read by two independent readers, and the opaque zone counts compared as described by Moran *et al.* (2005). With otoliths collected more recently (i.e. 2006/07 and 2007/08 seasons), a single reader-reference collection approach was used. Here, prior to reading any batch of 'new' otoliths, an experienced reader read a subset of sections randomly selected from a reference collection (n = 150, 're-familiarisation reading'). Counts were compared with previously agreed counts, and bias and precision measured. In cases of clear bias or low precision (IAPE > ~8-9%), another 150 reference collection sections were read, and bias and precision again estimated. Once the required level of bias and precision had been achieved, all the 'new' sections were read once and a random selection (25%) read for a second time, and bias and precision again measured ('production reading').

The estimated age of individual oceanic pink snapper was calculated using otolith increment counts as follows. Firstly, opaque zone counts for fish collected during the peak period of opaque increment deposition with either 'opaque' or 'wide translucent' otolith margins were adjusted by adding 1 to those counts. The age class (i.e., age of fish in whole years) was then determined as the adjusted count based on the knowledge that a single opaque zone is formed annually (Wakefield 2006). The biological age (i.e. age in decimal years), was determined by adding the period of time (in months, as a fraction of a year) between the assumed birth date (August 1) and month of capture (Wakefield 2006).

### *Spangled emperor*

A reference set of otolith sections was created from otoliths that when read independently by three experienced readers achieved an acceptable level of precision (IAPE < 5.5%) and lack of significant drift as determined from age bias plots. The upper bound of acceptable IAPE was then revised to 5.78% for this species, derived from the largest unbiased IAPE from initial paired readings of the reference collection done by the experienced readers (where 47.2% of readings achieved exact agreement, 45.3% had discrepancies of 1 and 7.5% had discrepancies of 2, for counts ranging from 1 to 30 increments). Analysis of imprecision and bias (drift) of repeated readings from the reference set was used to assess competency of the primary age reader (Reader 1) prior to commencing subsequent age readings following a break of at least 2 weeks. Once qualified as having acceptable precision and accuracy, Reader 1 then read all otolith sections once, followed by an independent set of repeated readings of a random 25% sub-sample. Otolith reading was done in batches of at least 200 otolith sections. Precision and drift were checked for these paired readings for each batch and if acceptable, the first set of opaque increment counts of that batch was accepted for age estimation. Otherwise, Reader 1 re-trained prior to continuing with new counts until acceptable levels of precision and no significant drift were recorded.

The method for calculating age estimates from otolith increment counts is described in Marriott *et al*. (2010) and Marriott *et al.* (2011a). Firstly, counts of annually deposited opaque increments (annuli) on otoliths collected during the peak period of opaque increment deposition with "wide translucent" marginal increments were adjusted for late-forming opaque increments by adding 1 to those counts. The age class (i.e., age of that fish in whole years) was then determined as the adjusted count, since the duration from birth to deposition of the first annulus, and from the deposition of one annulus to the next, was determined to be approximately annual (Marriott *et al.* 2011a). The biological age, in decimal years, was determined by adding to the age class the length of time (to the nearest month, as a fraction of a year) calculated from when the most recently formed annulus was deposited to the time when the fish died.

### *Goldband snapper*

A single set of counts of the opaque zones in otoliths was conducted by a single experienced reader (SN) following the necessary training or re-training using a reference collection of otoliths. The reference collection was comprised of otolith sections that had been interpreted in a manner that was consistent with those sampled and aged from the Kimberley fishery in North-Western Australia, which had been previously shown to produce accurate estimates of fish age (Newman and Dunk 2003). To assess the repeatability of increment counts, a random set of these counts was then repeated by the primary age reader for 163 otoliths, which constituted 11.5% of the entire set of goldband otoliths collected, aged and analysed for this report. Precision in opaque zone counts between repeated readings by the primary age reader was estimated using an IAPE while reader drift was investigated using age-bias plots.

The method for calculating age estimates from otolith increment counts for goldband snapper in the Kimberley is described in Newman and Dunk (2003). For Gascoyne goldband snapper, counts of annually deposited opaque increments (annuli) on otoliths collected during the peak period of opaque increment deposition with "wide translucent" marginal increments were adjusted for late-forming opaque increments by adding 1 to those counts. From an analysis of the timing of the spawning season and annulus deposition, the average age when the first annulus was deposited in otoliths of goldband snapper sampled from the Gascoyne Bioregion was determined to be 5 months. The biological age, in decimal years, was determined by adding to the adjusted annulus count the length of time (to the nearest month, as a fraction of a year) calculated from deposition of the most recently formed annulus to the time when the fish died and then subtracting from this the difference between 1 and the average fraction of a year (in months) lived until deposition of the first annulus. The age class was then calculated as the biological age rounded down to the nearest whole year.

### 4.2.2 Gonads

For the three demersal indicator species, paired gonads were dissected, examined macroscopically, sexed and weighed (nearest 1 g). Gonads of pink snapper and goldband snapper were macroscopically staged based on methods described in Mackie *et al.* (2009), and of spangled emperor based on the methods described in Mackie and Lewis (2001). Samples of fresh, unfrozen gonads of pink snapper (inner gulf stocks only, females only), spangled emperor (both sexes), and a small number of goldband (females only), either whole or as 2-3 mm transverse medial sections, were fixed in 10% buffered formaldehyde-seawater for subsequent histological processing and microscopic analysis.

Transverse sections of pink snapper ovaries were prepared as described in Mackie *et al.* (2009). Sections were examined microscopically and staged on basis of their histological characteristics (Mackie *et al*. 2009). Transverse sections of preserved spangled emperor gonads were prepared and categorised into maturity stages based on microscopic criteria as described in Marriott *et al.* (2010). Batch fecundity was estimated using the hydrated-oocyte method (Hunter *et al.* 1985; Mackie *et al*. 2009) for pink snapper from the inner gulfs (see 5.1.4.2) and for a small number of spangled emperor only.

## 4.3 Logbook data collection

Commercial (since 1975) and charter (since 2002) fishing catch and effort data were provided to DoFWA on a monthly basis in the form of statutory logbook returns that are completed and submitted by the skippers or the owner of the fishing licence. The landed form of product (eg. fillet, whole) and sum of unload weights for each species caught in a month are recorded separately for commercial fishing by different methods (eg. drop line, hand line) for each vessel. Commercial fishing is also reported within grid map blocks delineated by degree lines of latitude and longitude (i.e. approximately 60 x 60 nautical mile 'blocks') for each vessel. Landed catches of pink snapper that are reported on commercial logbook returns (submitted every month) and on catch disposal records (CDRs: submitted after every trip) are compared for data checking and quality control. CDRs are required to be submitted for the purpose of monitoring catch quota of pink snapper upon completion of each fishing trip and, as part of the regulations for the SBSF, all pink snapper catch must be accurately weighed on unloading. Corresponding effort information (days fished, hours fished per day, etc.) was also recorded for each record of catch. On charter fishing logbook returns data were recorded on a daily basis and for fishing done within 5 x 5 nautical mile blocks or, for all fishing done in marine parks and reserves, by GPS coordinate for each fishing location. The lengths (TL, mm) of all, or a random sample, of fish that were retained by charter fishers were recorded on their daily/trip returns. Copies of the logbook returns for commercial and charter fishing are provided in Appendix 2.

Recreational fishing data were provided from surveys conducted by the DoFWA (e.g. RFS: see Section 6.1.2.2. for further details). Recreational data were also provided by volunteer fishers participating in the Research Angler Program (RAP). In 2007 a dedicated effort was made by the Department to implement the RAP in the Gascoyne Bioregion, including the use of RAP angler logbooks and RAP catch cards (not reported here) by recreational fishers. This work was supported by an external grant provided by the NRM Rangelands Catchment Coordinating Group, enabling the appointment of a dedicated RAP coordinator to be based in the Gascoyne. Recreational fishers recorded the TL of each species caught and released or retained and details of the time and location of fishing and fishing gear used in RAP angler logbooks. RAP logbook data were used to estimate (given certain assumptions; see Section 6.3) the size-selectivity of spangled emperor caught by recreational fishers, but were not used directly in catch curve or per-recruit quantitative assessment models. This project also enabled the biological dataset for spangled emperor to be supplemented and a collaborative study between the DoFWA and CSIRO on fine-scale patterns in population genetics of spangled emperor at Ningaloo to be conducted (Berry *et al.* 2012).

## 4.4 Analyses – Rationale for spatial and temporal grouping of data

Because catch and effort data (C&E) from the three sectors were reported and collected within different time periods, much consideration was given to how best to group both the biological and fishery data to allow meaningful comparisons and the most appropriate representations for each sector. Grouping commercial data based on the Shark Bay Snapper Fishery quota-year (i.e. 1 September to August 31) most appropriately represents annual totals of commercial C&E in the Gascoyne because it reflects historical periods of setting and allocating catch quota for this fishery (representing the major commercial demersal scalefish fishing activity in the Bioregion). Conversely, grouping recreational data based on the timeframe during which the Gascoyne recreational fishing survey data were collected, i.e. 1 April 2007 to March 31 2008, most appropriately represents the annual estimates of recreational C&E. Charter fishing is currently managed as part of the recreational sector and is therefore most appropriately represented over the same time period as recreational fishing (i.e. 1 April – 31 March).

Since peak fishing activity occurs in winter for all sectors in the Bioregion, primarily because strong winds in the off-peak season between October and May (AIMS unpublished data in Smallwood 2009) impede water-based activities, comparisons of annual C&E between sectors were made for 'years' with coincident winter periods (i.e. "Overlap period" in Fig. 4.1). Thus, data for the commercial year 1 September 2006 to 31 August 2007 were compared to data for recreational and charter years commencing 1 April 2007 ending 31 March 2008 (Fig. 4.1). In all cross-sector comparisons, the coincident months were April-August inclusive and the disparate months (occurring in different calendar years) were September-March inclusive. This approach assumed that the inter-annual influence of variation from C&E data reported for the months September to March had negligible influence on comparisons of the general properties of annual C&E estimates between sectors.

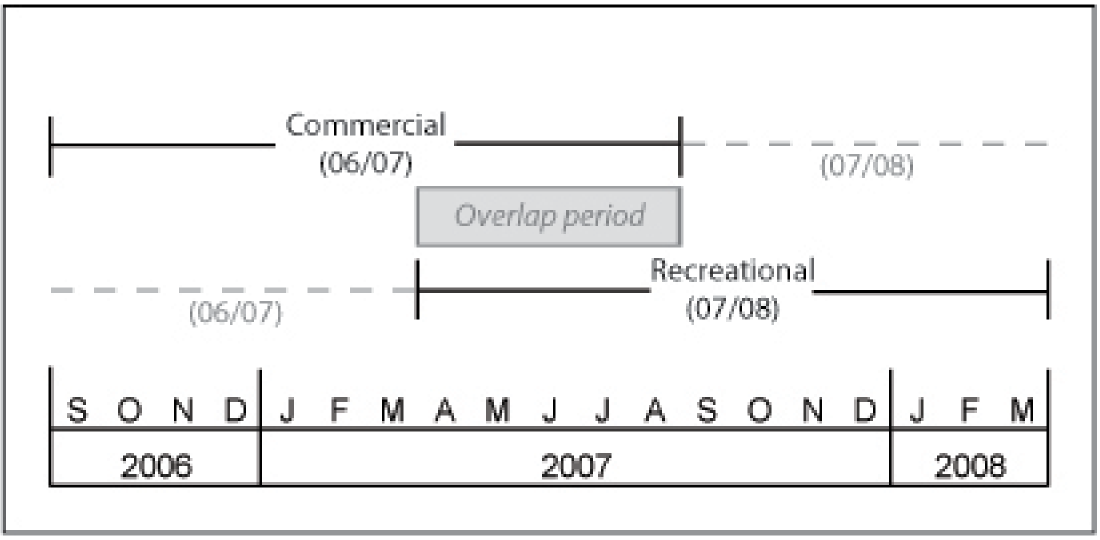



**Figure 4.1.** Periods used for reporting annual catch, effort and biological statistics. Data from the commercial sector were reported for "Commercial" years (1 September to 31 August) and data from the recreational and charter sectors were reported for "Recreational" years (1 April to 31 March). "Overlap period" represents the periods of peak catches and fishing effort across all sectors.

This assumption was explored for catch curve assessments of spangled emperor and goldband snapper stocks, where the analyses were repeated for different types of assessment year (calendar, recreational, commercial). Those analyses revealed that results were relatively robust to decisions made concerning which monthly samples to include or exclude based on year type, supporting this assumption (Section 6.3; Appendices 3, 4). The sensitivity of the pink snapper assessment models to different year type groupings will be explored in future assessments (i.e. 2012 onwards).

Fishery boundaries often do not match bioregional, zone or regional management boundaries, may not coincide with statistical catch and effort reporting block boundaries, or two or more existing fishery boundaries may not coincide or may overlap. These are true of the Gascoyne Coast Bioregion, where a range of existing managed fisheries harvest demersal scalefish species (Section 3.0).

Extensive discussions among researchers and managers of the DoFWA resulted in the assessment zones presented in Figure 1.1. The justifications for these assessment zone boundaries are as follows:

- Bioregional boundaries (e.g. the Gascoyne Coast Bioregion) were developed as part of the regional management initiative during the early 2000's (DoF. 2000; Lenanton *et al.* 2006).
- The Shark Bay Inner Gulfs comprise Zone 1. The boundary between the inner gulfs and oceanic waters of Shark Bay was developed through a protracted process that took into consideration the best available understanding of the distribution of the oceanic and inner gulf stocks of pink snapper (see 5.1.1 for details).
- The 250 m isobath boundary separating Zones 2 and 3 is consistent with that delineating the offshore demersal zone of the WCDSF (DoF 2010a), represents a common break in the distribution of fishes and habitats and shift in fishing activity as few recreational fishers currently operate beyond this depth. This boundary is also consistent with the recommended western management boundary for the GDSF (DoF 2005).

- The Pt Maud to Tantabiddi commercial fishing closure was implemented in the early 1970s in anticipation of the declaration of the Ningaloo Marine Park (DoF 2006). The line at Pt Maud is also the proposed northern boundary for the GDSF (DoF 2005) and thus was selected as the boundary separating Zones 1-4 (South Gascoyne) from Zones 5-7 (North Gascoyne).
- Zones 4 and 5 comprise waters within the Ningaloo Marine Park that are respectively adjacent to open, and closed commercial fishing areas. Preliminary data from RFS surveys suggest that some recreational fishers launching from Zone 4 access deep water adjacent to the zone, suggesting the break between Zones 4 and 5 be maintained for the purpose of these assessments.

The boundaries among the various management zones rarely match existing 1-degree CAES blocks (used to collect commercial catch and effort data), or the 5 x 5 nm blocks used to collect both angler, and charter catch and effort information. Thus a set of decision rules was developed to consistently enable the precise allocation of the available catch and effort data from each sector and assessment zone for reporting (see Section 6.1.2). Additionally, the Commonwealth-managed Western Deepwater Trawl Fishery harvests demersal scalefish species and its area of operation is restricted to depths deeper than the 200 m isobath. No data from this fishery were included in this report.

## 4.5 Analyses – Rationale for adopting different assessment approaches for the different indicator species

Different assessment approaches were applied to the different stocks of indicator species in this report. The different approaches reported here reflected different amounts of data availability in each of these cases and thus were consistent in general concept with the multi-tiered approaches to assessment and monitoring adopted by Smith *et al.* (2008). The primary fishing sector (recreational, charter, commercial) from which landed catches were sampled and analysed for stock assessments varied among indicator species, reflecting the varying cross-sector compositions of landed catches among these species (Table 3.1). Accordingly, assessments for pink snapper stocks focussed primarily on commercial and recreational data, assessments for spangled emperor focussed mainly on recreational data, and assessments for goldband snapper focussed mainly on commercial data (Table 3.1). Catch and effort data, however, were analysed from all sectors for comparative purposes.

Because pink snapper has historically been the primary demersal scalefish target species in the Bioregion, DoFWA had implemented research and monitoring programs on those stocks since the 1980s. Thus, a much longer time series of datasets were available for this species. Additionally, a long time series of suitable CPUE data identified as representing a reliable index of relative abundance, once standardised, were also available for pink snapper. This meant that there were sufficient data available for an assessment of pink snapper stocks using an integrated age-structured model (Section 6.3.1). However, there were insufficient CPUE data available for spangled emperor and goldband snapper to use for this purpose (see Section 6.2), which meant that Level 3 ‘weight-of-evidence’ (Wise *et al.* 2007) assessment approaches were applied to those stocks (see Section 6.3 for details). Importantly, in developing the ‘weight-of-evidence’ approach, the DoFWA acknowledges that advice on stock status based on smaller datasets and simpler methods than for stocks assessed using an integrated age-structured model (e.g., as used for pink snapper stocks herein) have greater uncertainty. The ‘weight-of-evidence’ approach accounts for a higher unquantified level of uncertainty in simpler, lower-level assessments (represented in Tables 7.1 - 7.5 of this report).

Separate assessments were done for each stock of indicator species. Assessments for the pink snapper stock in oceanic waters (Zone 2) and for each of the three pink snapper stocks in the inner gulfs of Shark Bay (Eastern Gulf, Denham Sound, Freycinet Estuary; Zone 1) were done using integrated models. A Level 3 weight of evidence assessment of the goldband snapper stock was done for its oceanic stock, comprising Zones 2 and 3 only, because commercial goldband catches north of Point Maud (Zones 5–7) represent commercial fishing by Pilbara fishers, which contribute to a separately managed fishery that is monitored and managed under separate processes. A separate Level 3 'weight-of-evidence' assessment was done for spangled emperor north ("North Gascoyne": Zones 5-7) and south ("South Gascoyne": Zones 2-4) of Point Maud because of known differences in biology (Marriott *et al.* 2011a) and historical fishing and management between these two study regions.

Where possible, catch and effort statistics were reported for each sector and assessment zone for each indicator species. However, when there were insufficient data per zone or issues with assessment zone boundaries splitting spatial reporting units, these data were presented for groupings of assessment zones that were within or aligned with spatial stock assessment units (see Section 6).

# 5.0 Biological characteristics of key indicator species

## 5.1 Pink snapper

The biological information for pink snapper in the Gascoyne Coast Bioregion that is presented in this report was mostly derived from research undertaken by Wakefield (2006, for oceanic waters off Shark Bay) and Jackson (2007, for the inner gulfs of Shark Bay) and is cited accordingly. In contrast to the other two indicator species, intensive biological sampling of pink snapper was not specifically undertaken as part of the Gascoyne IFM project.

### 5.1.1 Distribution, structure and movement

Pink snapper are widely distributed throughout the warm temperate and sub-tropical waters of the western Indo-Pacific (Paulin 1990). Around southern Australia, pink snapper inhabit marine embayments and coastal waters out to depths of ca. 250-300 m from Hinchinbrook Island in Queensland (18° S) to Barrow Island in Western Australia (21° S) (Kailola *et al.* 1993). The species has been reported in commercial catches from waters as far north as Derby (14° S, D. Gibson pers. comm.).

The stock structure of pink snapper in the Gascoyne Coast Bioregion, which is located towards the northern extent of the abundant geographic range of the species on the west coast of Australia, has received considerable attention. Comprehensive stock identification studies, mostly focused in and around Shark Bay, and conducted over more than 20 years, have shown the stock structure of this species to be highly complex in this region (Jackson 2007). A number of independent genetic (allozymes) studies indicate that pink snapper in the oceanic waters off Shark Bay, in the Eastern Gulf and Freycinet Estuary, are reproductively isolated from each other, while fish in Denham Sound are partially isolated from the other populations (MacDonald 1980; Johnson *et al.* 1986; Whitaker and Johnson 1998; Baudains 1999). Tagging studies (Moran *et al.* 2003; G. Jackson unpublished data) and otolith chemistry (Edmonds *et al.* 1999; Bastow *et al.* 2002; Gaughan *et al*. 2003) indicate little or no mixing of juvenile, sub-adult and adult pink snapper between oceanic waters and the inner gulfs, or between the two inner gulfs. Hydrodynamic modelling in combination with empirical data obtained via ichthyoplankton surveys showed that pink snapper eggs and larvae in the inner gulfs are retained within meso-scale eddies (kilometres in diameter) effectively isolating the main spawning grounds from each other (Nahas *et al*. 2003).

As a consequence of these studies, four separate fishable stocks of pink snapper are recognised within the Gascoyne Coast Bioregion: an oceanic stock found along the continental shelf outside Shark Bay and, in the inner gulfs, separate stocks in the Eastern Gulf, Denham Sound and Freycinet Estuary (Stephenson and Jackson 2005). The biological data reported here are presented for the oceanic and inner gulf stocks separately. The exact nature of the relationship between pink snapper off Shark Bay and along the west coast is being investigated as part of a Western Australian Marine Science Institute sub-project (WAMSI 4.4.2, 'Implications of mobility, stock structure, and biology of West Coast indicator species for management'). Results of this WAMSI research will be used to re-assess stock and management boundaries for pink snapper in Gascoyne and West Coast Bioregions in the future.

### 5.1.2 Age and growth

#### 5.1.2.1 Introduction

Age and growth of pink snapper have been comprehensively studied in New Zealand (Paul 1992; Francis *et al.* 1992) and Australia (McGlennon *et al.* 2000; Sumpton 2002; Ferrell 2004; Fowler *et al.* 2004) including Western Australia (Wakefield 2006; Jackson 2007; Lenanton *et al.* 2009a). The interpretation of annuli in sectioned sagittal otoliths is widely used for ageing pink snapper around Australia (Coutin *et al.* 2003; Fowler *et al.* 2004; Lenanton *et al.* 2009a). The species is long-lived and relatively slow growing. Maximum age recorded in Australia is ca. 40 years (Norriss and Crisafulli 2010) compared with ca. 55-60 years in New Zealand (Francis *et al.* 1992).

#### 5.1.2.2 Methods

For the pink snapper samples collected (Table 5.1.1), sex was determined and ages were estimated using the methods outlined in Chapter 4.0. Growth was modelled by fitting von Bertalanffy growth curves to length (FL, mm) at age data,

$$\mathrm{FL} = L_\infty(1-e^{-K(t-t_0)})$$

for oceanic (Wakefield 2006) and inner gulf snapper (Jackson *et al.* 2010b). Juveniles for which sex could not be determined were randomly assigned to either the male or female sets of length-at-age data. Growth curves and parameters were compared using a likelihood-ratio test (Kimura 1980) under the assumption that the residual variances differed (Cerrato 1990).

#### 5.1.2.3 Results

##### 5.1.2.3.1 Contribution of samples from each sector

Biological samples from the inner gulf stocks were mostly obtained by fishery-independent sampling undertaken by DoFWA (research program commenced in 1997) due to the absence of a significant commercial fishery for this species inside Shark Bay, difficulties in adequately sampling recreational catches and the highly restrictive management measures in place since ca. 1998 (e.g. moratorium on take of pink snapper in Eastern Gulf 1998-2003) (Table 5.1.1). The exception was the Freycinet Estuary where a significant proportion of the samples collected during 1997-2000 were obtained from recreational catches landed at the Nanga boat ramp. Since 2004, inner gulf samples have only been collected by DoFWA during DEPM surveys that are undertaken approximately every 3-5 years.

All biological samples from the oceanic stock were obtained via fishery-dependent sampling of commercial catches taken by SBSF vessels, which take approximately 80-90% of the total overall catch. In general, greater numbers of samples were collected each year from 2004 onwards following a reduction in the TACC to closely monitor stock recovery and meet requirements under the *Environment Protection and Biodiversity Conservation Act 1999.*

**Table 5.1.1.** Number of biological samples of pink snapper from the Gascoyne Coast Bioregion by stock, sector and year used in the assessments reported. Sample numbers here only represent fish that were individually aged.

| Stock | Sector | Year | | | | | | | | | | | | | | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1992 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | |
| Oceanic | Commercial | 200 | 557 | – | – | 88 | – | 242 | – | 201 | 610 | 477 | 687 | 323 | 618 | 98 |
| | Recreational | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 |
| | Research | – | – | – | – | – | – | – | – | – | – | – | – | 13 | 67 | 2 |
| | Total | 200 | 557 | – | – | 88 | – | 242 | – | 201 | 610 | 477 | 687 | 336 | 685 | |
| Inner Gulfs | | | | | | | | | | | | | | | | |
| Eastern Gulf | Commercial | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 |
| | Recreational | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 |
| | Research | – | – | – | 113 | 81 | 265 | 104 | 103 | 186 | 250 | – | – | – | – | 100 |
| | Total | | | | 113 | 81 | 265 | 104 | 103 | 186 | 250 | – | – | – | – | |
| Denham Sound | Commercial | – | – | 10 | – | – | – | – | – | – | – | – | – | – | – | 1 |
| | Recreational | – | – | – | 50 | – | – | – | – | – | – | – | – | – | – | 7 |
| | Research | – | – | 59 | 97 | 86 | 252 | 67 | – | 107 | – | – | – | – | – | 92 |
| | Total | – | – | 69 | 147 | 86 | 252 | 67 | – | 107 | – | – | – | – | – | |
| Freycinet Estuary | Commercial | – | – | – | – | – | – | – | – | – | – | – | – | – | – | 0 |
| | Recreational | – | – | 76 | 54 | 79 | 179 | 9 | 11 | – | – | – | – | – | – | 43 |
| | Research | | | 11 | 10 | 48 | 2 | 57 | 70 | – | 119 | – | 106 | 110 | – | 57 |
| | Total | | | 87 | 64 | 127 | 181 | 66 | 81 | – | 119 | – | 106 | 110 | – | |
| | Grand total | 200 | 557 | 156 | 324 | 382 | 698 | 479 | 184 | 494 | 979 | 477 | 793 | 446 | 685 | |

### 5.1.2.3.2 Bias and precision

***Oceanic stock***

In general, otoliths of pink snapper from oceanic waters of Shark Bay are more difficult to interpret than otoliths from inner gulf fish. No significant trend in bias was evident from the age bias plot for the majority of the otoliths from the most recent year used in the assessment (i.e. 2007/08 season) (Fig. 5.1.1). However, sections with more than 12 opaque zones (i.e. older fish) were generally poorly represented in commercial catches. The overall IAPE value at 4.18% was below the target level recommended for species with intermediate (10-30 years) to long (> 30 years) life spans and with otoliths of moderate reading complexity.

***Inner gulf stocks***

Similarly, no significant trend in bias was evident from the age bias plots for otoliths of fish from the ‘age classes’ taken by the recreational fishery from the three inner gulf stocks (data for all years combined) (Fig. 5.1.1). Sections with more than 12 opaque zones were poorly represented in the Eastern Gulf and Denham Sound samples while sections with more than 20 opaque zones were consistently represented in samples from the Freycinet Estuary. Measures of precision were well below the target level for sections from the Eastern Gulf (IAPE = 2.3%) and Freycinet Estuary (IAPE = 4.4%) but higher for Denham Sound (IAPE = 6.2%) reflecting differences in otolith readability among the locations/stocks.

#### 5.1.2.3.3 *Validation*

The periodicity of increment formation in pink snapper otoliths from Gascoyne waters has been validated as annual using marginal increment analysis and oxytetracycline/calcein marking of otoliths (Wakefield 2006; Jackson 2007). Opaque zones are generally formed during late autumn to early spring; delineation typically was completed by August-September in oceanic waters and over a longer period, August-November, in the inner gulfs (Wakefield 2006; Jackson 2007).

#### 5.1.2.3.4 *Length and age composition of stock*

There were no obvious sex-based biases in length frequency distributions with males and females observed equally across the length ranges sampled for all four stocks (Fig. 5.1.2). The benefits of fishery-independent sampling in the inner gulfs were apparent with fish less than the minimum legal length (MLL, 500 mm TL) well represented in the Eastern Gulf and Denham Sound. Samples from the oceanic stock that were obtained from fishery-dependent sampling contained no fish less than the MLL (410 mm TL). Equal proportions of both sexes were taken above the MLL and in the case of inner gulf stocks, also above the maximum legal length (750 mm TL).

Modal age was youngest at 4 years for the oceanic stock (samples from 2007/08 season) followed by 6 years in Denham Sound (samples from 2003), 8 years in Eastern Gulf (samples from 2004) and 10 years in Freycinet Estuary (samples from 2007) (Fig. 5.1.3). The age frequency distribution for the oceanic stock indicated a steady decline in age classes after the mode although fish older than 15 years were represented but in very low numbers. In the inner gulfs, fish older than ca. 15 years were absent in the Eastern Gulf and poorly represented in Denham Sound while fish of 20 years or more were observed in the Freycinet Estuary.

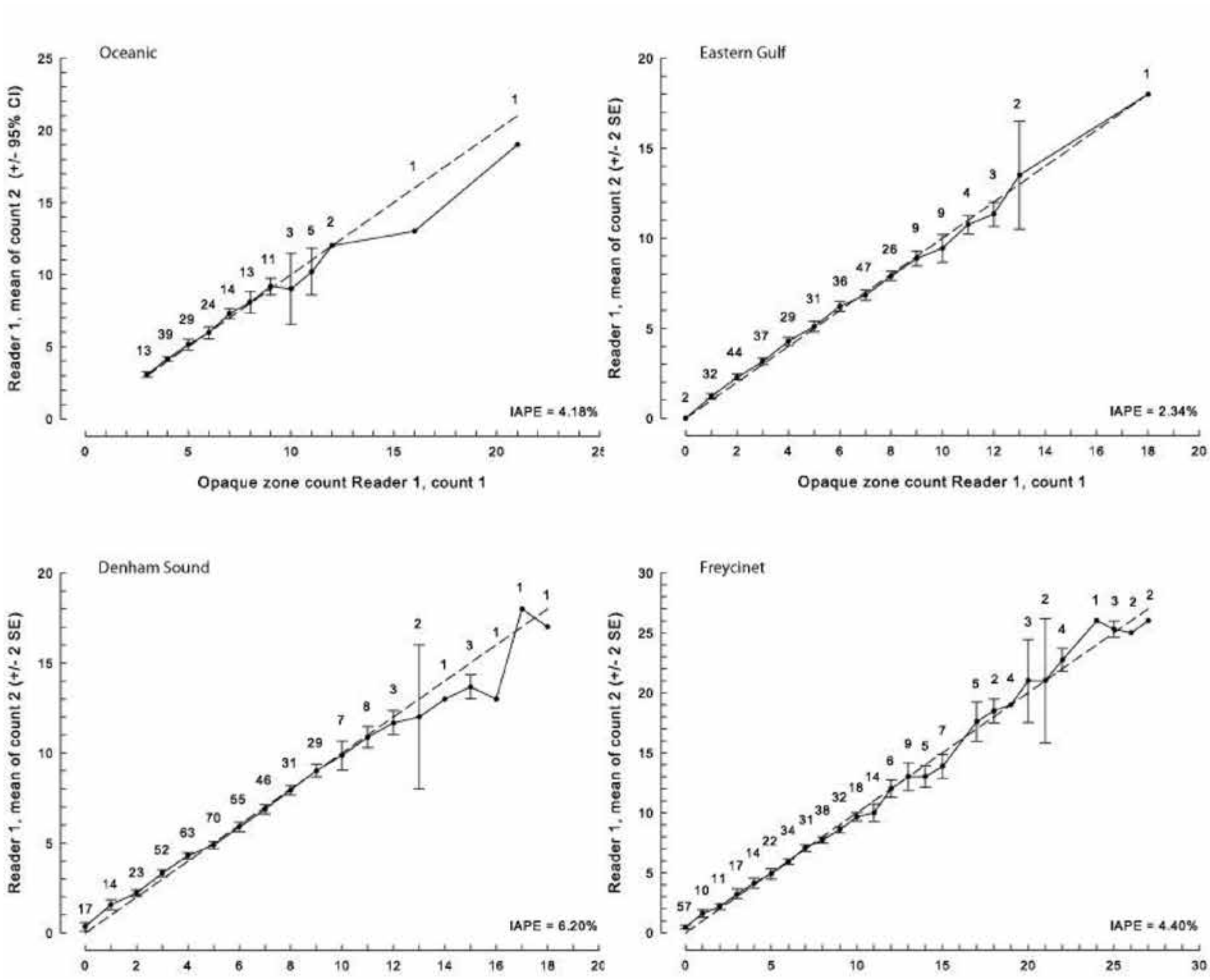



**Figure 5.1.1.** Age bias plots for repeat readings of pink snapper otoliths (i) upper left, oceanic stock, samples collected 2007/08 commercial season, single reader 25% re-read (total n=685, re-read n = 104, IAPE = 4.18), (ii) upper right, Eastern Gulf, single reader, all sections read twice (n=312, IAPE = 2.34), (iii) lower left, Denham Sound, single reader, all sections read twice (n=427, IAPE = 6.20), (iv) bottom right, Freycinet Estuary, single reader, all sections read twice (n=353, IAPE = 4.4). Numbers above points are sample sizes. Error bars represent ±2 SE; lack of bars in some cases indicates insufficient data for some count groups.

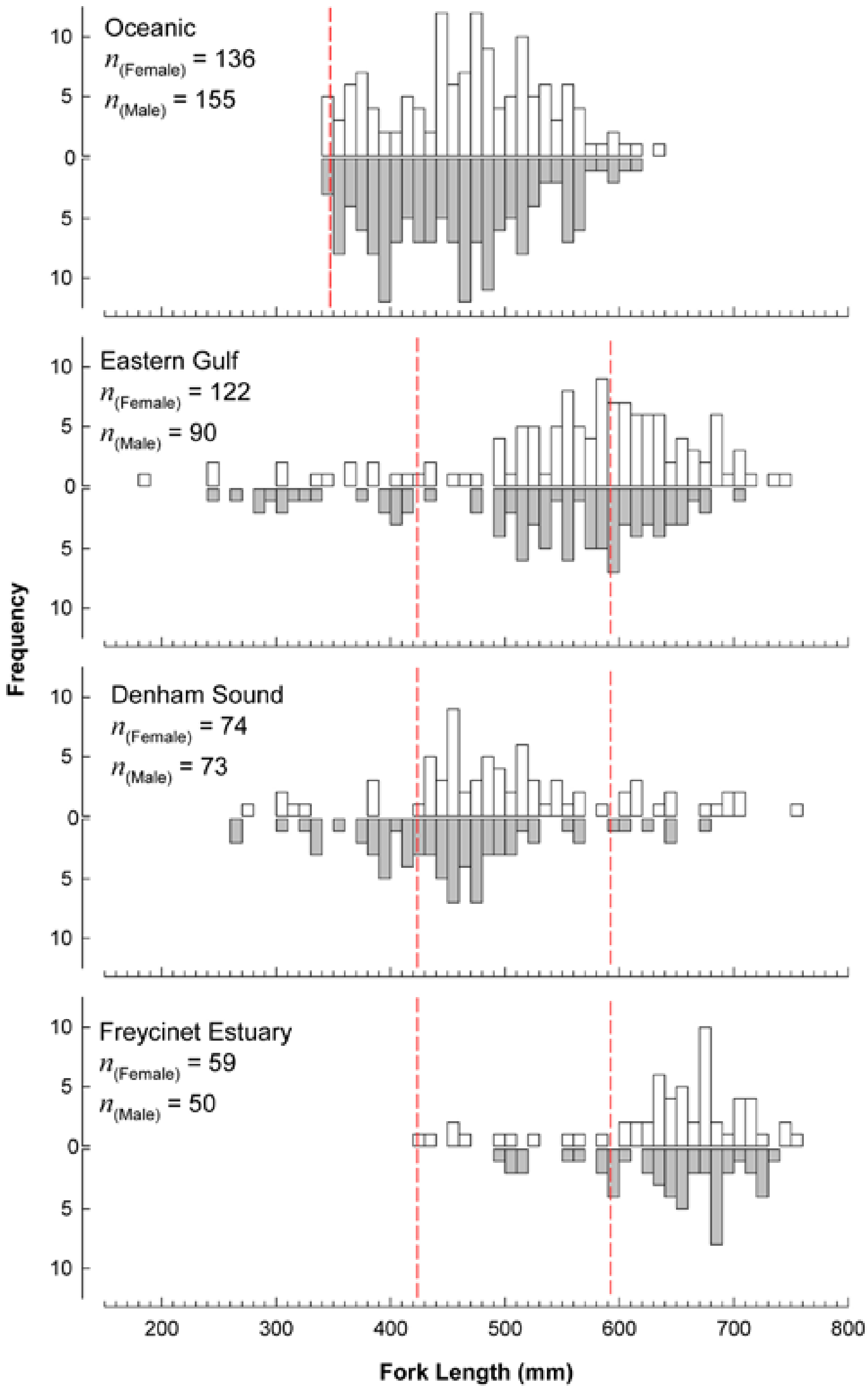



**Figure 5.1.2.** Length frequency distributions for female (white bars, above x-axis) and male (grey bars, below x-axis) pink snapper from the oceanic stock (data from most recent year 2007/08 in assessment), Eastern Gulf (from 2004), Denham Sound (from 2003) and Freycinet Estuary (from 2007). Hatched red lines indicate minimum and maximum legal lengths (applies only in inner gulfs) as FL equivalents of TL).

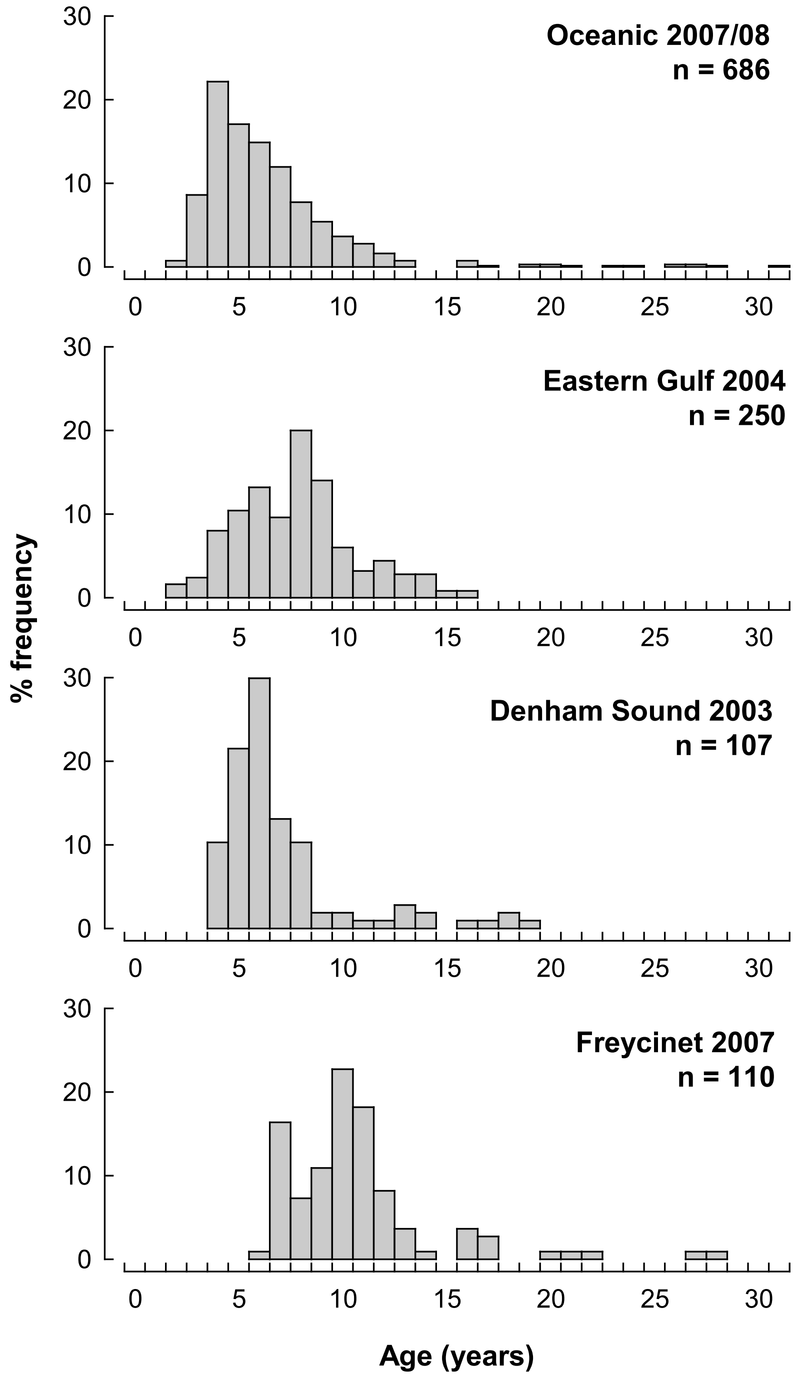



**Figure 5.1.3.** Age frequency (%) distributions of pink snapper from oceanic stock, Eastern Gulf, Denham Sound and Freycinet Estuary.

### 5.1.2.3.5 Growth

The von Bertlanffy growth curves fitted the length-at-age data reasonably well in all cases: coefficients of determination were generally high (> 0.8) and the mean extrapolated ages at zero length were close to zero in most instances (Table 5.1.2). In general, growth was rapid with fish up to ca. 4-5 years of age in all four stocks. Thereafter, growth slowed between 5-10 years prior to reaching an asymptotic length at ca. 9-10 years with oceanic fish and later, at ca. 14-15 years with inner gulf fish (Fig. 5.1.4). Maximum age was ca. 30 years in the Freycinet Estuary and oceanic stock compared with 19 years in Denham Sound and 17 years in the Eastern Gulf.

In the inner gulfs, sex-based differences in growth were not statistically significant in the Eastern Gulf and Freycinet Estuary but were in Denham Sound (Jackson *et al.* 2010b). Growth of both females and males was not significantly different between the Eastern Gulf and Freycinet Estuary but differed significantly for both sexes between these areas and Denham Sound (Jackson *et al.* 2010b). Growth in both sexes in Denham Sound was slower compared with the Eastern Gulf and the Freycinet Estuary. For oceanic fish, differences in growth between the sexes were also statistically significant (Wakefield 2006). (Note: stock assessment models for inner gulf pink snapper stocks are single sex. Although the last oceanic pink snapper stock assessment (2009) was modified to accommodate differences in growth between sexes based on evidence from Wakefield (2006), the benefits of sex-based differences in model parameters will be fully explored in the next full assessment (i.e. 2012)).

#### 5.1.2.3.6 Natural mortality

Natural mortality ($M$) was directly estimated, $M$ = 0.22 (95 C.I. 0.09-0.34) year$^{-1}$, by fitting catch curves to pink snapper age structure data collected during a 5-year fishing moratorium in the Eastern Gulf (Jackson 2007). For comparison, indirect estimates of $M$ obtained using the empirical equations of Pauly (1980, assuming a mean water temperature of 23$^{o}$ C), Ralston (1987) and Hoenig (1983, assumed $Z = M$) were 0.51, 0.38 and 0.12 year$^{-1}$, respectively (using a common maximum age of 35 years). The integrated stock assessment models currently used for management of the inner gulf snapper stocks employ values of $M$ = 0.08–0.19 year$^{-1}$ (Stephenson and Jackson 2005). Stock assessment modelling with the oceanic snapper stock uses $M$ = 0.13 year$^{-1}$. In contrast, a value of $M$ = 0.075 year$^{-1}$is used in snapper stock assessments in New Zealand (Gilbert et al. 2000), where individuals of the species live to 55-60 years of age (Francis R.I.C.C. et al. 1992) compared with around 30 years in Shark Bay.

**Table 5.1.2.** von Bertalanffy growth parameters (± 95% CI) for pink snapper from the Gascoyne Coast Bioregion.

| | $L_\infty$ (mm, FL) | $k$ (year$^{-1}$) | $t_o$ (year) | $A_{max}$ | $FL_{max}$ | n | $r^2$ |
|---|---|---|---|---|---|---|---|
| *Oceanic* | | | | | | | |
| Female | | | | | | | |
| Estimate | 599 | 0.214 | -0.144 | 30.0 | 725 | 726 | 0.89 |
| Upper | 617 | 0.231 | -0.075 | | | | |
| Lower | 580 | 0.199 | -0.216 | | | | |
| Male | | | | | | | |
| Estimate | 561 | 0.244 | -0.079 | 22.1 | 710 | 661 | 0.88 |
| Upper | 588 | 0.274 | 0.012 | | | | |
| Lower | 537 | 0.218 | -0.156 | | | | |
| *Eastern Gulf* | | | | | | | |
| Female | | | | | | | |
| Estimate | 755 | 0.178 | 0.035 | 17.2 | 698 | 523 | 0.91 |
| Upper | 782 | 0.192 | 0.146 | | | | |
| Lower | 732 | 0.165 | -0.049 | | | | |
| Male | | | | | | | |
| Estimate | 751 | 0.172 | -0.071 | 15.2 | 749 | 385 | 0.93 |
| Upper | 784 | 0.187 | 0.009 | | | | |
| Lower | 724 | 0.158 | -0.133 | | | | |
| *Denham Sound* | | | | | | | |
| Female | | | | | | | |
| Estimate | 762 | 0.142 | -0.032 | 19.1 | 721 | 384 | 0.85 |
| Upper | 795 | 0.157 | 0.108 | | | | |
| Lower | 728 | 0.129 | -0.170 | | | | |
| Male | | | | | | | |
| Estimate | 660 | 0.181 | -0.055 | 17.1 | 563 | 297 | 0.84 |
| Upper | 722 | 0.209 | 0.091 | | | | |
| Lower | 615 | 0.151 | -0.189 | | | | |
| *Freycinet Estuary* | | | | | | | |
| Female | | | | | | | |
| Estimate | 773 | 0.166 | 0.125 | 29.7 | 730 | 392 | 0.94 |
| Upper | 791 | 0.176 | 0.205 | | | | |
| Lower | 759 | 0.156 | 0.044 | | | | |
| Male | | | | | | | |
| Estimate | 766 | 0.173 | 0.075 | 31.1 | 724 | 399 | 0.95 |
| Upper | 780 | 0.182 | 0.146 | | | | |
| Lower | 756 | 0.164 | 0.009 | | | | |

$L_\infty$ hypothetical asymptotic length at infinite age, FL, fork length, $k$, growth coefficient, $t_o$, hypothetical age at zero length, $A_{max}$, maximum age, $FL_{max}$, maximum fork length, $n$, sample size, $r^2$, coefficient of determination.

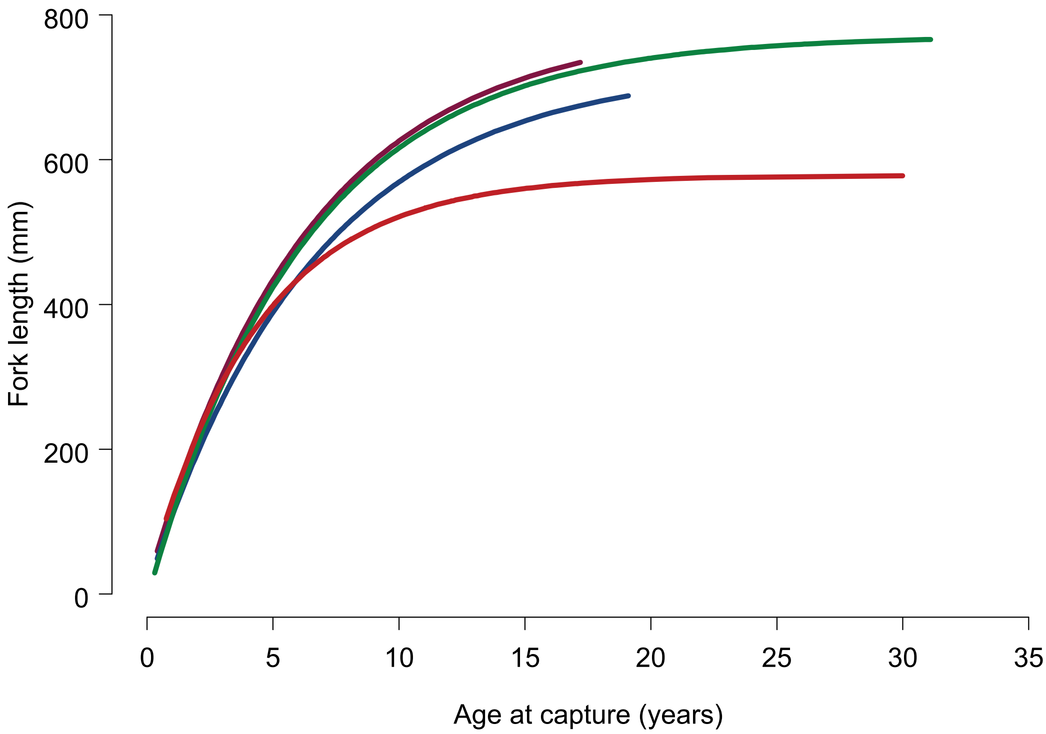



**Figure 5.1.4.** von Bertalanffy growth curves (sexes combined) for pink snapper from Eastern Gulf (purple), Freycinet Estuary (green), Denham Sound (blue) and oceanic stock (red).

### 5.1.3 Recruitment

During spawning, the pelagic eggs of pink snapper are released and fertilized within the upper layers of the water column (Smith 1986; Jackson 2007). The incubation period is influenced by environmental conditions, particularly water temperature, with hatching taking place after ca. 20-30 hrs in the inner gulfs (Norriss and Jackson 2002). A pelagic larval phase of ca. 20-25 days (Tapp 2003) occurs prior to metamorphosis and settlement when the juveniles are ca. 8-10 mm in length (TL) (Fukuhara 1991; Battaglene and Talbot 1992).

Studies in Australia (Fowler and Jennings 2003; Hamer and Jenkins 2004; Saunders 2009) and New Zealand (Francis 1993) have shown high levels of inter-annual variability in 0+ recruitment. While the driving mechanism(s) are still not fully understood, environmental factors, in particular, water temperature, has been linked with recruitment variation. Warmer years either during the spawning season or shortly thereafter, have been linked with stronger recruitment, and conversely, cooler years with weaker recruitment in New Zealand (Francis 1993) and southern Australia (Fowler and Jennings 2003; Hamer and Jenkins 2004; Saunders 2009).

Research on recruitment variability with pink snapper in the sub-tropical Shark Bay region and possible linkages with environmental conditions is still at a preliminary stage. The distribution and abundance of juveniles in their first and second years (0+ and 1+) has been investigated in the inner gulfs using trawl (Moran and Kangas 2003) and trap surveys (Jackson *et al.* 2007). Moran and Kangas (2003) concluded that in the Freycinet Estuary, 0+ fish reside in the deeper basins (depth 10-12 m) over sandy/muddy bottoms from the time of settlement (ca. 20 days) until well after their first birthday. In contrast, and possibly due to the greater range of suitable habitat types that are available, in Denham Sound and the Eastern Gulf, 0+ fish delay their movement into the deeper waters until their first summer (ca. 6 months of age) and remain there until their second summer (ca. 18 months of age).

Trawl surveys conducted in the deeper waters during February-March were judged to provide representative samples of 0+ abundance and were therefore determined to be the preferred method to be used to develop an annual index of 0+ abundance in all three areas (Jackson *et al.* 2007). The longest time series of recruitment data for pink snapper in the Gascoyne is that for the Freycinet Estuary that indicates a single strong recruitment year only (in 2000, Moran and Kangas 2003) in 13 years of trawl surveys (Fig 5.1.5). The 2000-year class was strongly represented in recreational catches landed at Nanga as 6 year olds in 2006 and 7 year olds in 2007 (G Jackson unpublished data). Similar such time series of juvenile recruitment data are unavailable for the other two inner gulf stocks or the oceanic stock; establishing locations of higher densities of 0+ in Denham Sound, Eastern Gulf and waters off Carnarvon using trawl and trap surveys have been less successful (Moran and Kangas 2003; Jackson *et al.* 2007) but the research continues.

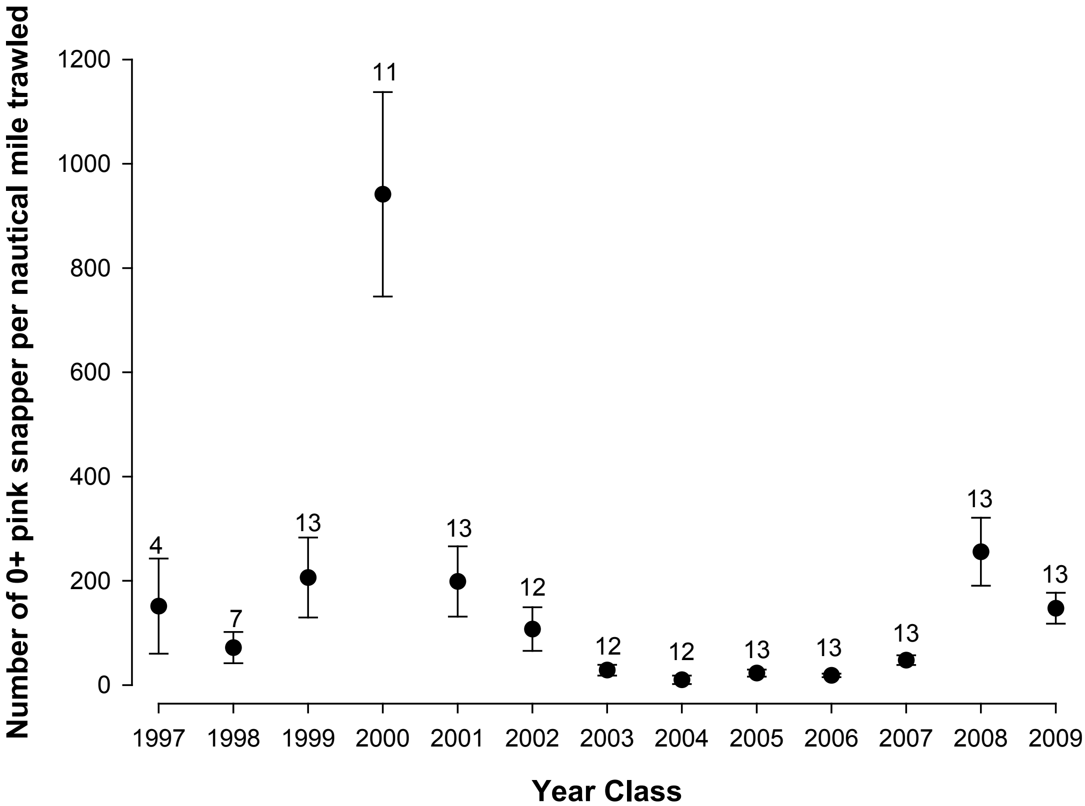



**Figure 5.1.5.** Index of *Pagrus auratus* 0+ recruitment in Freycinet Estuary, Shark Bay, based on annual trawl surveys. Error bars are 1 SE and numbers above data points are number of trawl shots undertaken in each year.

Recruitment of oceanic pink snapper has also been investigated using more indirect methods. Moran *et al.* (2005) used a form of cohort analysis (i.e. Pope's approximation, Pope 1972) to analyse a time series of catch-at-age data from the commercial SBSF snapper fishery for the period 1982-2003. Results showed a period of high recruitment in early 1990s followed by low recruitment through the mid-late 1990s and early 2000s (Moran *et al.* 2005). More recent stock assessment modelling (P. Stephenson, unpublished data) indicates only average or below average recruitment since 2000 (see 6.3.3). At this time, and based on the very limited information available, stronger recruitment years appear to occur approximately 8-10 years apart for pink snapper populations in the sub-tropical waters of the Shark Bay region. Additionally, specific patterns in annual recruitment appear not to be consistent between the oceanic and inner gulf stocks.

### 5.1.4 Reproduction

#### 5.1.4.1 Introduction

The reproductive biology of pink snapper has been studied extensively in New Zealand (Cassie 1956; Crossland 1977a, 1977b; Scott and Pankhurst 1992; Scott *et al.* 1993) and Australia (Sumpton 2002; Coutin *et al.* 2003; McGlennon 2003), including Western Australia (Wakefield 2006; Jackson 2007; Lenanton *et al.* 2009a). The species is functionally gonochoristic with protogynous sex inversion occurring in some individuals prior to maturity (Francis and Pankhurst 1988). The species has an annual reproductive cycle and is a batch spawner (Scott and Pankhurst 1992; Jackson 2007). Spawning occurs around winter in sub-tropical waters (e.g. Queensland, Sumpton 2002; Shark Bay, Jackson *et al.* 2010b) and in spring-summer in temperate waters (e.g. New Zealand, Scott and Pankhurst 1992; South Australia, McGlennon 2003; south coast of Western Australia, Wakefield 2006). Pink snapper commonly form spawning aggregations where sex ratios (females by weight) range between 1:1 and 1:6 (Jackson *et al*. 2012).

#### 5.1.4.2 Methods

Gonadosomatic indices (GSIs) were calculated for males and females using,

$$GSI = 100 \times W_g/(WW - W_g)$$

where WW = whole wet weight of fish (g) and $W_g$ = wet weight of gonads (g) for fish ≥ length at 50% maturity ($L_{50}$). Mean monthly GSIs were compared with the monthly percentage frequencies of fish with developed (male stage 3, female stage 4) or spawning (male stage 4, female stage 5) gonads for all fish ≥ $L_{50}$ (Jackson *et al.* 2010b).

Lengths ($L_{50,}$ $L_{95}$) and ages at maturity ($A_{50,}$ $A_{95}$) were estimated using logistic regression analysis with 95% confidence limits estimated using bootstrapping (Jackson *et al*. 2010b). Length and age at maturity for both sexes were compared using a likelihood-ratio test (Kimura 1980; Cerrato 1990) with the significance level adjusted for multiple comparisons using the Bonferroni method (Quinn and Keough 2003).

Batch fecundity was estimated gravimetrically using the hydrated-oocyte method for inner gulf fish only (to provide information required for daily egg production method assessments, see 6.3) (Mackie *et al* 2009). Non-linear regression models were used to describe the relationship between batch fecundity (*F*) and fork length (*FL*) for females from each inner gulf stock. Regression curves were compared among years 1998-2003 and stocks using the approach described by Jackson (2007).

#### 5.1.4.3 Results

##### 5.1.4.3.1 Annual reproductive cycles

***Oceanic stock***

Seasonal trends in the mean GSIs and the monthly proportions of females with gonads in spawning condition indicated that spawning occurs between May-September and peaks in June-July (Wakefield 2006, Fig. 5.1.6).

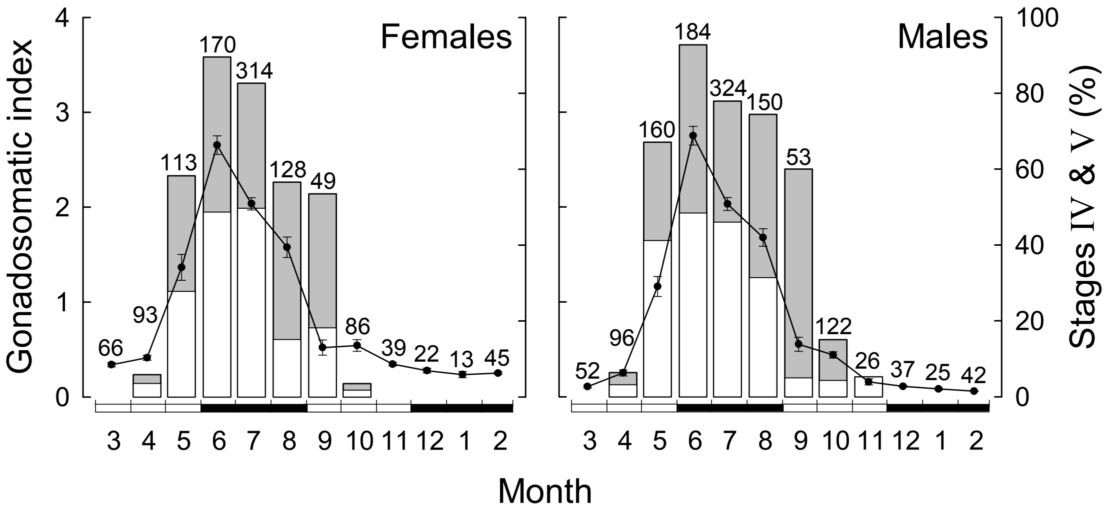



**Figure 5.1.6.** Mean monthly gonadosomatic indices (±1 SE) and the percentage of mature (white bars) or spawning (grey bars) gonads of female (left) and male (right) *Pagrus auratus* from the oceanic stock off Carnarvon, Western Australia (from Wakefield, 2006). The data have been pooled for corresponding months (sample sizes shown) and are limited to fish $\geq L_{50}$ for each sex separately. On the x-axis, open rectangles represent spring and autumn, and black rectangles winter and summer.

***Inner gulf stocks***

Spawning in the Eastern Gulf and Denham Sound mostly occurs between May-July, whereas, fish in the Freycinet Estuary mostly spawn later in the year, between August-October (Jackson *et al* 2010, Fig. 5.1.7).

#### 5.1.4.3.2 Length and age at maturity

***Oceanic stock***

The differences in the mean length and age at 50% maturity between sexes were not significant (Table 5.1.3). Female size at maturity was lower in oceanic fish compared with inner gulf fish while for males size at maturity was higher in oceanic fish compared with Eastern Gulf and Denham Sound but not the Freycinet Estuary. Female age at maturity was higher in oceanic fish compared with Eastern Gulf but lower than for Denham Sound and the Freycinet Estuary. Male age at maturity was higher in oceanic fish than in all inner gulf fish.

***Inner gulf stocks***

There were significant differences in the mean length and age at 50% maturity between sexes with females being consistently larger and older than males in all three areas (Table 5.1.3). Based on estimates derived using reproductive data pooled over the 8-year study, both sexes matured at significantly smaller lengths and younger ages in the Eastern Gulf compared with Denham Sound and the Freycinet Estuary (Jackson *et al*. 2010b).

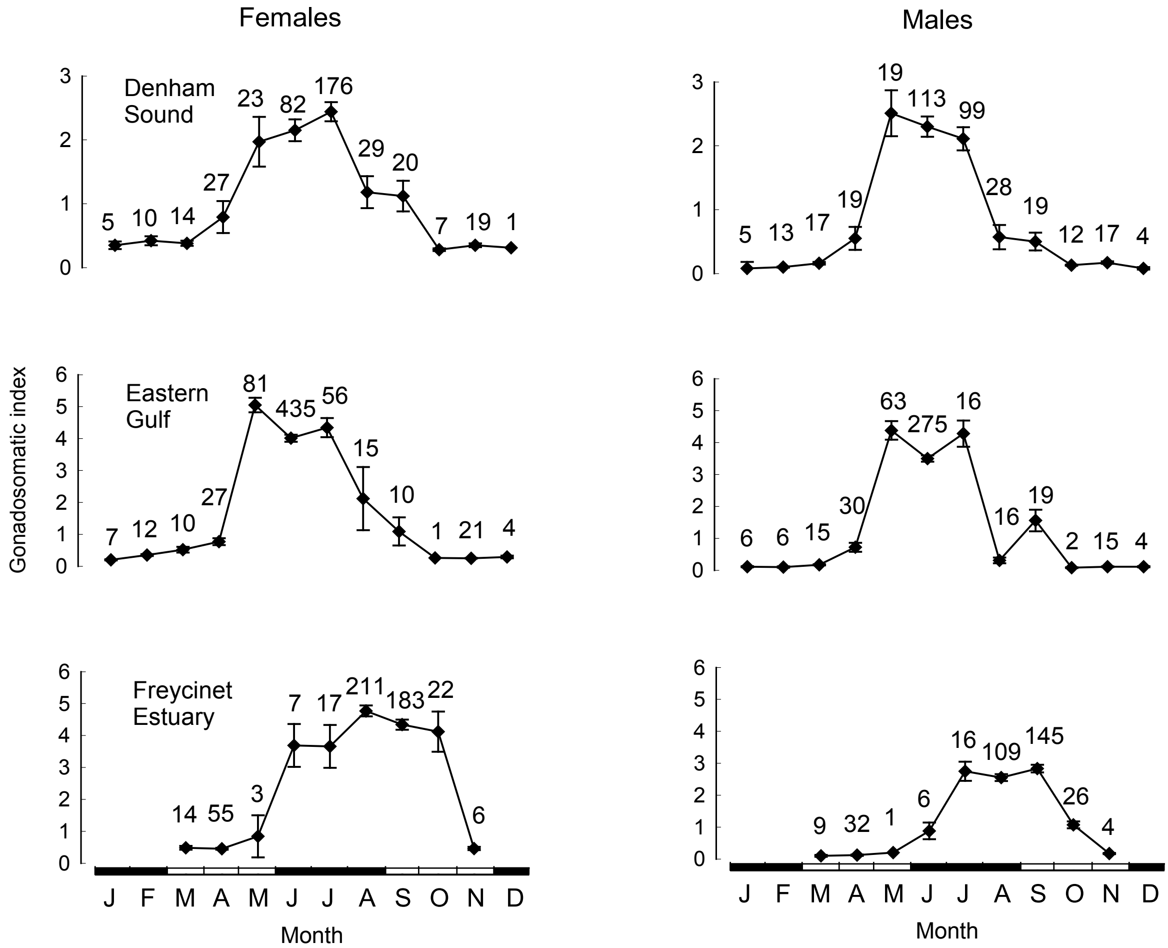



**Figure 5.1.7** Mean monthly gonadosomatic indices (±1 SE) for pink snapper from inner gulfs (Denham Sound, Eastern Gulf and Freycinet Estuary), based on fish with lengths ≥ length at 50% maturity (from Jackson *et al.* 2010b). On *x*-axis, closed rectangles represent winter and summer months; open rectangles, spring and autumn months. Numbers are sample sizes in each month.

**Table 5.1.3.** Lengths and ages at which 50% and 95% ($L_{50}$, $L_{95}$, $A_{50}$ and $A_{95}$ respectively) of female and male pink snapper reach sexual maturity in the Gascoyne Coast Bioregion. Information is presented for oceanic stock (from Wakefield 2006) and inner gulfs stocks (from Jackson 2007). Lengths are FL (mm) and age (years) and n = sample size.

| | $L_{50}$ | $L_{95}$ | *n* | $A_{50}$ | $A_{95}$ | *n* |
|---|---|---|---|---|---|---|
| Oceanic | | | | | | |
| Female | | | | | | |
| Estimate | 327 | 417 | 1010 | 4.0 | 6.0 | 406 |
| Upper | 336 | | | | | |
| Lower | 317 | | | | | |
| Male | | | | | | |
| Estimate | 305 | 418 | 938 | 3.9 | 6.2 | 418 |
| Upper | 317 | | | | | |
| Lower | 294 | | | | | |
| Eastern Gulf | | | | | | |
| Female | | | | | | |
| Estimate | 348 | 484 | 689 | 3.2 | 5.6 | 309 |
| Upper | 365 | 500 | | 3.5 | 6.0 | |
| Lower | 330 | 464 | | 2.7 | 5.0 | |
| Male | | | | | | |
| Estimate | 243 | 403 | 599 | 1.6 | 4.2 | 225 |
| Upper | 267 | 429 | | 2.2 | 5.2 | |
| Lower | 218 | 374 | | 1.0 | 3.1 | |
| Denham Sound | | | | | | |
| Female | | | | | | |
| Estimate | 401 | 601 | 482 | 5.5 | 9.9 | 202 |
| Upper | 417 | 629 | | 6.1 | 11.8 | |
| Lower | 384 | 572 | | 4.9 | 8.4 | |
| Male | | | | | | |
| Estimate | 276 | 397 | 380 | 2.7 | 7.1 | 139 |
| Upper | 295 | 423 | | 3.3 | 8.9 | |
| Lower | 259 | 369 | | 1.6 | 5.5 | |
| Freycinet Estuary | | | | | | |
| Female | | | | | | |
| Estimate | 420 | 566 | 580 | 4.5 | 8.4 | 213 |
| Upper | 452 | 587 | | 5.1 | 9.2 | |
| Lower | 392 | 542 | | 3.8 | 7.4 | |
| Male | | | | | | |
| Estimate | 330 | 465 | 522 | 2.7 | 5.9 | 178 |
| Upper | 352 | 436 | | 3.3 | 7.5 | |
| Lower | 301 | 489 | | 2.0 | 4.4 | |

### 5.1.4.3.3 Fecundity

Based on the female gonad samples (n = 408) collected in 1998-2003 from the inner gulfs (Table 5.1.4), batch fecundity (F) was positively related to female fork length (FL) in all cases. There was no significant difference in the non-linear relationship between FL and F either among sampling years or locations/stocks. Batch fecundity data from all locations/years (Fig 5.1.8) was therefore pooled and a common non-linear model derived as follows:

$F = 9.436 \times 10^{-5} FL^{3.359}$

Estimated batch fecundity ranged from 2,749 hydrated oocytes (1 SE 577) for a 172-mm-FL female (Eastern Gulf, 1998) to 653,261 hydrated oocytes (1 SE 52,225) for a 710-mm-FL female (Freycinet Estuary, 1998) (Table 5.1.4).

**Table 5.1.4.** Estimates of batch fecundity (*F*) for pink snapper from inner gulfs of Shark Bay from samples collected 1998-2003.

| Area | Year | *n* | *FL* range (mm) | *F* range (eggs x $10^3$) |
|---|---|---|---|---|
| Eastern Gulf | 1998 | 91 | 172 - 696 | 3 - 429 |
| | 1999 | 45 | 348 - 714 | 23 - 531 |
| | 2000 | 41 | 284 - 706 | 18 - 424 |
| | 2001 | - | - | - |
| | 2002 | 14 | 396 - 710 | 22 - 293 |
| | 2003 | 45 | 193 - 636 | 2 - 331 |
| Denham Sound | 1998 | 22 | 241 - 638 | 2 - 277 |
| | 1999 | - | - | - |
| | 2000 | 27 | 341 - 619 | 4 - 474 |
| | 2001 | - | - | - |
| | 2002 | - | - | - |
| | 2003 | 22 | 437 - 701 | 21 - 416 |
| Freycinet Estuary | 1998 | 37 | 473 - 741 | 15 - 653 |
| | 1999 | 18 | 343 - 685 | 8 - 543 |
| | 2000 | 14 | 195 - 670 | 4 - 265 |
| | 2001 | - | - | - |
| | 2002 | 32 | 432 - 725 | 32 - 660 |
| | 2003 | - | - | - |

*n* = sample size; *FL* = fork length

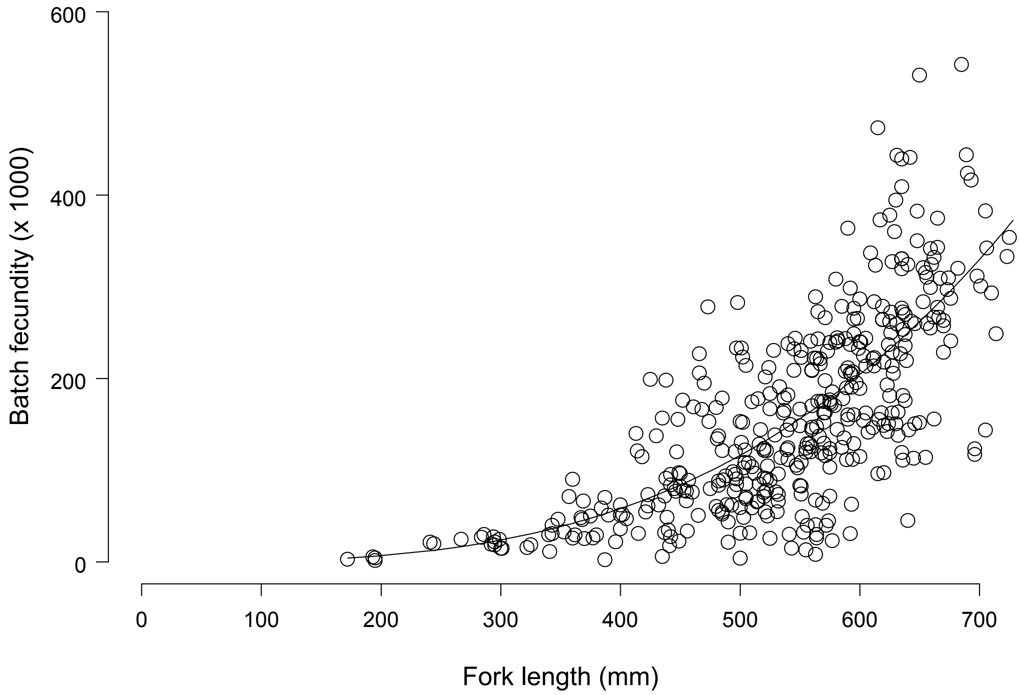



**Figure 5.1.8.** Relationship between batch fecundity and fork length (mm) for pink snapper from the inner gulfs (Eastern Gulf, Denham Sound and Freycinet combined) pooled for years 1998-2003. Solid line is common non-linear regression curve.

### 5.1.5 Other factors influencing susceptibility to exploitation

Size (length) and daily bag limits are used in the management of recreational fisheries for pink snapper in the Gascoyne, both in the inner gulfs (slot* and daily bag limit apply) and in oceanic waters (minimum legal length [MLL] and daily bag limit apply); the same MLL applies in the commercial SBSF in oceanic waters. Management arrangements involving limits on the size or numbers of fish that can be retained typically assume nil or very low levels of discard (post-release) mortality. However, information on the post-release mortality is often unavailable.

While a range of factors influence discard mortality, e.g. handling and hooking injuries, capture depth via barotrauma has been shown to be the most important factor (Stewart 2008; Lenanton *et al.* 2009b). Pink snapper are considered to be more robust than many other demersal species although discard mortality rates related to barotrauma still increase significantly with depth; in WA waters, mortality increased from ca 3% in shallow depths (5-30 m) to ca. 69% in deeper waters (45-65 m) (Lenanton *et al.* 2009b).

In the shallow waters of the inner gulfs (mostly < 20 m), discard mortality due to barotrauma is not considered to be significant, as with this species elsewhere (e.g. Stewart 2008; Grixti *et al.* 2009). In oceanic waters, research has focussed on providing information on discard rates in the commercial SBSF; the fishery accounts for approximately 80-90% of the total pink snapper catch and operates to a greater extent in the deeper waters (30-300 m) compared to the recreational/charter fishery (mainly undertaken in waters 30-70 m).

* Minimum legal lengths for inner gulf and oceanic stocks are above the estimated lengths at 50% maturity.

Preliminary analysis of data obtained from at-sea monitoring onboard SBSF vessels (n = 170+ drops since 2003, DoFWA unpublished data) indicates that the proportion of undersized (discarded) pink snapper decreased with the size of the catch (as fishers find schools of spawning snapper that typically form over nearshore reef habitat in shallower waters) but increased with increasing depth of water fished. The mean proportion of undersized pink snapper increased from ca. 11% in shallower waters (mean depth 63 m) when the species was the main target, to ca. 19% in deeper waters (mean depth 160+ m) when goldband snapper were the main target (DoFWA unpublished data).

The limited data available for recreational vessels fishing in similar oceanic waters (e.g. Levillian Shoals and off Steep Point, waters 30-60 m), obtained from exemption-returns lodged at the Denham Fisheries Office (2007), indicated that between 31% and 58% (average 47%) of pink snapper caught were discarded, i.e. significantly higher than discard rates with commercial vessels. Thus release mortality is likely a significant source of mortality for this species in deeper waters (i.e. > 30 m) across all fishing sectors in the Gascoyne Coast Bioregion.

## 5.2 Spangled emperor

### 5.2.1 Distribution, structure and movement

The spangled emperor has a circum-tropical distribution and in Western Australia (WA) is distributed from Rottnest Island northwards, typically in or near coral reef habitats (Allen and Swainston 1988). In WA, spangled emperor has been documented, from shallow water surveys (to 20 metres), to be most abundant in the Pilbara and Gascoyne Bioregions (Hutchins 2001). This includes areas such as the Monte Bello Islands, Muiron to Boodie Islands, Ningaloo to North-West Cape, Point Quobba to Coral Bay, and Western Shark Bay, as well as the South-West Kimberley and the Houtman Abrolhos Islands. In these areas spangled emperor is often found in places where sandy substratum meets patches of coral reef (Ayling and Ayling 1987).

The population structure and movement of spangled emperor in WA has been studied by assessing spatial variation in allozymes (Johnson *et al.* 1993), otolith microchemistry (Moran *et al.* 1993), tagging and recapture (Moran *et al.* 1993), acoustic telemetry (R. Babcock, R. Pillans unpublished data) and DNA micro-satellite markers (Berry *et al.* 2012). Individuals generally demonstrate a limited home range of less than three nautical miles (Moran *et al.* 1993). Relatively high site fidelity has been shown for at least some individuals in WA (R. Pillans unpublished data) and elsewhere (Chateau and Wantiez 2008). Limited mixing of post-settlement individuals is also indicated from an analysis of otolith microchemistry of spangled emperor sampled from different sites (Moran *et al.* 1993). Genetic studies have demonstrated homogeneous genetic characteristics across broad spatial scales (i.e., 10-1500 km) throughout its WA distribution (Johnson *et al.* 1993). Analysis of fine scale patterns using high resolution micro-satellite markers, however, has revealed that juveniles exhibit fine scale genetic autocorrelation, which declined with age (Berry *et al.* 2012). This implies both larval cohesion and extremely limited juvenile dispersal prior to maturity for the spangled emperor population, primarily in the vicinity of the Ningaloo Marine Park (Berry *et al.* in press). Further, hydrodynamic modelling showed that larvae were likely to be transported hundreds of kilometres, easily accounting for the observed gene flow, despite relatively restricted adult dispersal (Berry *et al.* 2012). This explains a causal mechanism for spangled emperor comprising a single genetic stock throughout the Bioregion and is consistent, in part, with the hypothesis of this species having a single genetic stock in WA.

### 5.2.2 Age and growth

#### 5.2.2.1 Introduction

Studies of the age and growth of spangled emperor populations have previously been undertaken in northwestern Australia (Moran *et al.* 1993), the Great Barrier Reef (Grandcourt 1999), Seychelles (Grandcourt 1999), the Red Sea (Salem 1999), southern Arabian Gulf (Grandcourt *et al.* 2006) and New Caledonia (Loubens 1980; Morales-Nin 1988). All of those studies used otolith sections to estimate fish age, which have been shown to produce accurate estimates for this species (Morales-Nin 1988; Grandcourt *et al.* 2006; Marriott *et al.* 2010) and reported spangled emperor to be a relatively long-lived, slow-growing scalefish in general. However, maximum estimates of age ranged from 14 (Grandcourt *et al.* 2006) to 27 (Loubens 1980) years and estimates of the von Bertalanffy growth parameter, $K$ ranged from 0.11 years$^{-1}$ (Grandcourt *et al.* 2006) to 0.22 years$^{-1}$ (Loubens 1980; Morales-Nin 1988), demonstrating some variability in reported estimates among studies.

This variation in reported growth estimates prompted the investigation of age and growth characteristics for spangled emperor in the two regions assessed for this report: South Gascoyne (Zones 1 to 4 combined) and North Gascoyne (Zones 5 to 7 combined; Fig 1.1). Results on age-growth characteristics for spangled emperor in the North Gascoyne and South Gascoyne have been published and are reported in Marriott *et al.* (2011a). Marriott *et al*. (2011a) found that spangled emperor was relatively long-lived with a maximum age of 30.75 years, that growth was significantly different between the study regions, with fish from the North Gascoyne demonstrating a higher $K$ and lower $L_{\infty}$ than those from the South Gascoyne, and no consistent significant effect of sex on growth.

Length frequency distributions of spangled emperor sampled from the catches of different sectors and representative catch-at-age distributions are presented to demonstrate the results of biological sampling for assessments in Section 6.3.

#### 5.2.2.2 Methods

Methods for sampling, biological processing and age estimation are reported in Section 4.

For representative catch-at-age distributions, details of statistical methods and rationale are reported in Marriott *et al*. (2011a). Data from only the recreational sector were considered due to sample size limitations and questions of representativeness of data collected from the other sectors. Recreational samples collected during interviews for the 2007/08 Recreational Fishing Survey (RFS), involved statistically designed random sampling stratified by month, location and mode of fishing (shore versus boat; as described in Section 4). As the RFS sampling design was stratified on known patterns of recreational fishing effort, this analysis assumed that landed recreational catches were directly proportional to landed recreational catches of spangled emperor (Marriott *et al.* 2011a).

Age samples from other sources of recreational sampling were only pooled with samples from the RFS if it was demonstrated that there were statistically non-trivial variation among them, while guarding against the prospect of Type II error ($\alpha$=0.25) inappropriately inflating the statistical power of subsequent tests (Winer *et al.* 1992; 1992). The number of pair-wise statistical comparisons (and thus recreational data groups included in the analysis) were restricted given considerations of experiment-wise error rates and to include only representative recreational datasets (Marriott *et al.* 2011a). Only 'like' groups were pooled within each region, given that the detection of a significant effect in one region was taken as evidence that this effect was non-trivial (Marriott *et al.* 2011a).

#### 5.2.2.3 Results

##### 5.2.2.3.1 Contribution of samples from each sector

The largest number of specimens collected by sector were reported in 2007, reflecting the greater amount of sampling effort in that year that was concomitant with the 2007/08 Recreational Fishing Survey (RFS) (i.e., Year 2; Table 5.2.1). All data in Table 5.2.1 are presented by Calendar year for comparison, in addition to the relevant sampling "years" used in / considered for analyses, which are in normal font type (i.e., data for charter and recreational sectors are consistently analysed by "Recreational" years and commercial data analysed by "Commercial" years; see Section 4.4 of General Methods).

**Table 5.2.1.** Numbers of spangled emperor obtained from North and South Gascoyne regions. RFS, recreational fishing survey, * Note: 2008 data to June only.

| Region | Sector | | Year type | Year 1 | Year 2 | Year 3 | % |
|---|---|---|---|---|---|---|---|
| North | Charter | | Recreational | 56 | 109 | | 14 |
| *Zones 5-6* | | | Calendar | 33 | 132 | | |
| | Commercial | | Commercial | | 3 | 79 | 7 |
| | | | Calendar | | 82 | | |
| | Recreational | | | | | | |
| | | RFS ramp | Recreational | 4 | 169 | | 15 |
| | | RFS roving | Recreational | | 34 | | 4 |
| | | Tournament | Recreational | 2 | 31 | | 2 |
| | | Donated/other | Recreational | 86 | 155 | 166 | 36 |
| | | RFS ramp | Calendar | | 162 | 11 | |
| | | RFS roving | Calendar | | 34 | | |
| | | Tournament | Calendar | | 25 | 8 | |
| | | Donated/other | Calendar | 6 | 172 | 229 | |
| | Research | | Calendar | 92 | 151 | | 21 |
| | Unspecified | | Calendar | 2 | | | 0.2 |
| | Total | | | 242 | 652 | 245 | 1139 |
| South | Charter | | Recreational | 18 | 57 | 7 | 11 |
| *Zones 2-4* | | | Calendar | 18 | 55 | 9 | |
| | Commercial | | Commercial | 36 | 112 | 55 | 28 |
| | | | Calendar | 135 | 13 | 55 | |
| | Recreational | | | | | | |
| | | RFS ramp | Recreational | 11 | 75 | | 12 |
| | | RFS roving | Recreational | 21 | 56 | | 11 |
| | | Tournament | Recreational | | 43 | 53 | 13 |
| | | Donated/other | Recreational | 20 | 157 | 3 | 25 |
| | | RFS ramp | Calendar | | 86 | | |
| | | RFS roving | Calendar | | 77 | | |
| | | Tournament | Calendar | | 43 | 53 | |
| | | Donated/other | Calendar | 14 | 158 | 8 | |
| | Research | | Calendar | | 3 | 5 | 1 |
| | Unspecified | | | | | | |
| | Total | | | 106 | 503 | 123 | 732 |
| Grand total | | | | 348 | 1155 | 368 | 1871 |

| Year type | Start Date | End Date | Common months | Year 1 | Year 2 | Year 3 |
|---|---|---|---|---|---|---|
| **Calendar** | 1 January | 31 December | April - August | 2006 | 2007 | 2008 |
| **Recreational** | 1 April | 31 March | April - August | 2006/07 | 2007/08 | 2008/09 |
| **Commercial** | 1 September | 31 August | April - August | 2005/06 | 2006/07 | 2007/08 |

#### 5.2.2.3.2 Bias and precision

Exact agreement was achieved from independent age readings of otoliths by the primary age reader for 69.4% of specimens, and discrepancies between repeated counts of 1, 2, and > 2 increments were made for 26.3%, 3.0%, and 1.3% of these specimens, respectively. The IAPE was comparatively low, at 2.56%, for the 25% of random sub-sampled paired readings, which was consistent with levels frequently tolerated by many ageing laboratories and reported in the literature (Campana 2001), indicating acceptable precision of the resulting age estimate data. Further, no significant or consistent trend in drift or bias from the exact agreement line was evident (Fig. 5.2.1.).

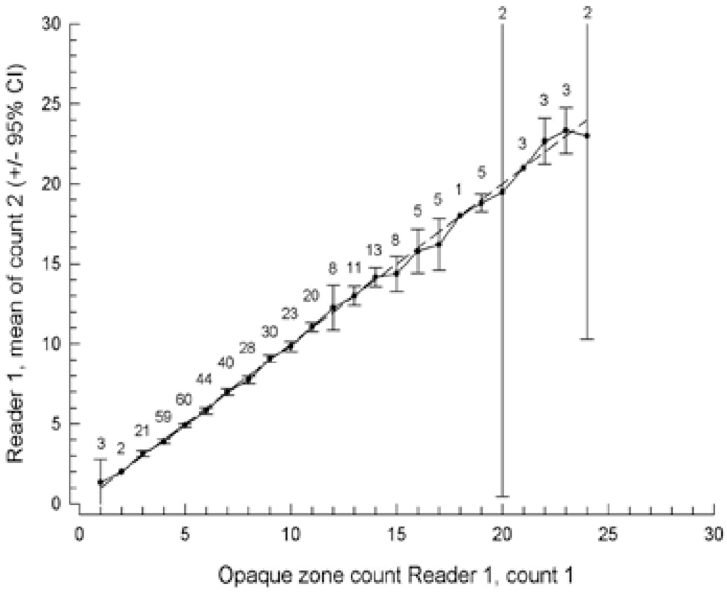



**Figure 5.2.1.** Age bias plot for subset of repeated readings of spangled emperor done by primary age reader (n = 399). IAPE = 2.56%. Numbers above each point represent numbers of otoliths read for groupings of count 1 data.

#### 5.2.2.3.3 Validation

Evidence supporting the accuracy of this age estimation method for spangled emperor populations in WA has been previously demonstrated (Kalish *et al.* 2002; Marriott *et al.* 2010; Andrews *et al.* 2011). Biological studies done elsewhere have also demonstrated that this method produces accurate age estimates for spangled emperor (Morales-Nin 1988; Grandcourt *et al.* 2006). Opaque zones in otoliths that are counted for estimates of fish age (years) are generally formed from October to December in the Gascoyne (Marriott *et al.* 2010).

#### 5.2.2.3.4 Length and age composition of stock

Inspection of pooled (i.e. from all collection sources) length frequency samples by sex demonstrated that males and females, as identified by macroscopic sex determinations, were observed across similar size ranges in both regions, with more small fish less than the MLL (i.e. to the left of the vertical dashed line) sampled from the North Gascoyne than from the South Gascoyne (Fig. 5.2.2.). There were conspicuously more females than males in the smallest length classes, and accurate microscopic sex determinations revealed that 100% of spangled emperor less than 200 mm FL were rudimentary or immature females, with intersexual fish (i.e., changing from female to male) sampled over a slightly larger, but relatively narrow, size range (251—274 mm FL; Marriott *et al.* 2010). This reflected pre-maturational protogynous sex change evident in at least the resident North Gascoyne population of this species and inaccurate macroscopic sex determinations for some of the smaller, younger fish (Marriott *et al.* 2010; see also Section 5.2.4.).

There was also a conspicuously higher number of larger fish sampled in the South Gascoyne than in the North Gascoyne and more females sampled than males in the largest length classes (Fig. 5.2.2**.**). The relatively uniform sex ratio throughout the harvestable size range (to the right of the red vertical dashed line indicating the MLL) demonstrates that fishing is not likely to impact more heavily on one sex than another as a consequence of this species' evolved sexual development. This was supported by the finding of no significant differences detected between male and female representative catch-at-length distributions for each of the study regions by Marriott *et al.* (2011a).

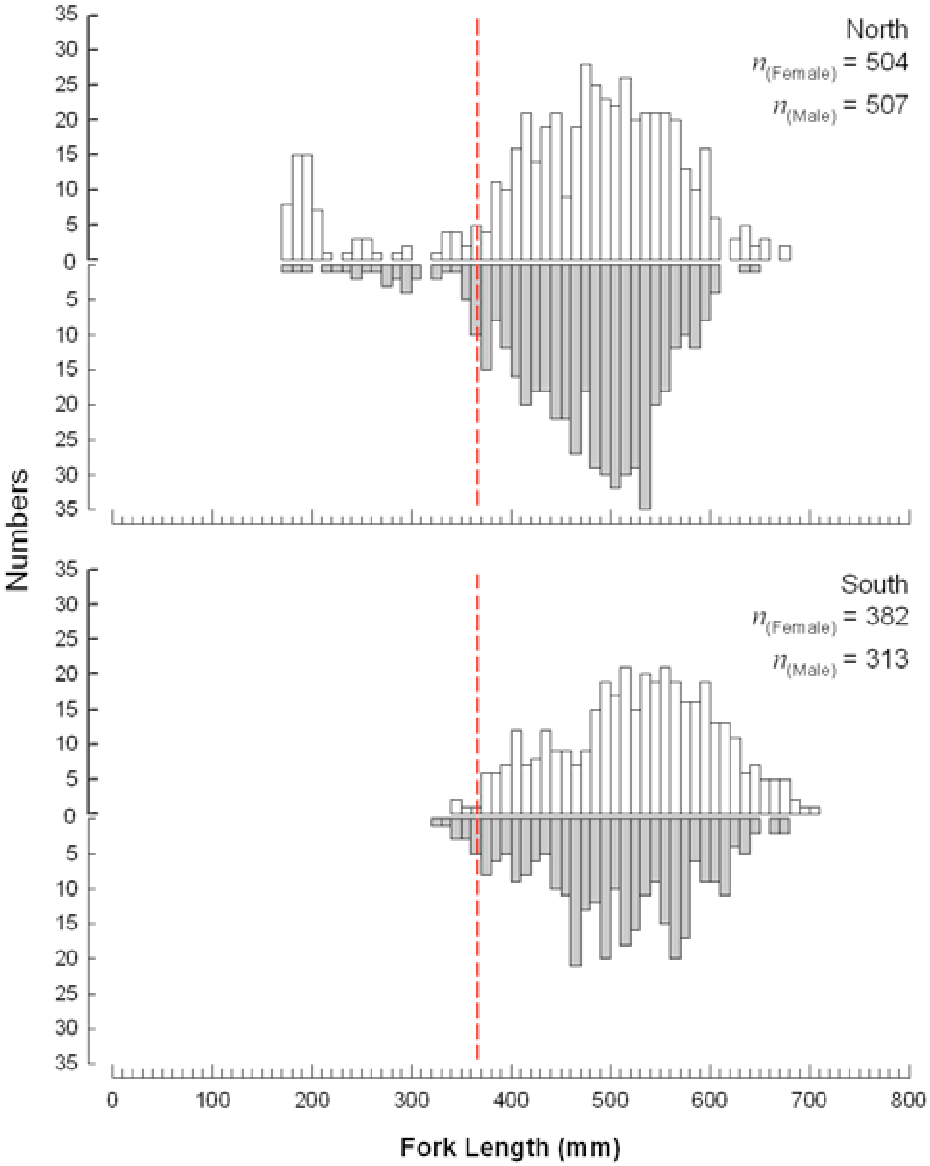



**Figure 5.2.2.** Length frequency distributions for female (white bars, above x-axis) and male (grey bars, below x-axis) for spangled emperor from the North Gascoyne and South Gascoyne assessment regions. Sexes determined from macroscopic inspection of gonads where it was not possible to obtain it from histological analysis. The red line represents the MLL of 410 mm TL, which equals 366.8 mm FL.

Very few specimens less than 350 mm FL were collected from the landed catches (Fig. 5.2.3) as this was below the current minimum legal size limit (MLL) of 41 cm TL, (which corresponds to 366.8 mm FL), except for targeted collections of smaller specimens by fishery-independent research sampling (Research).

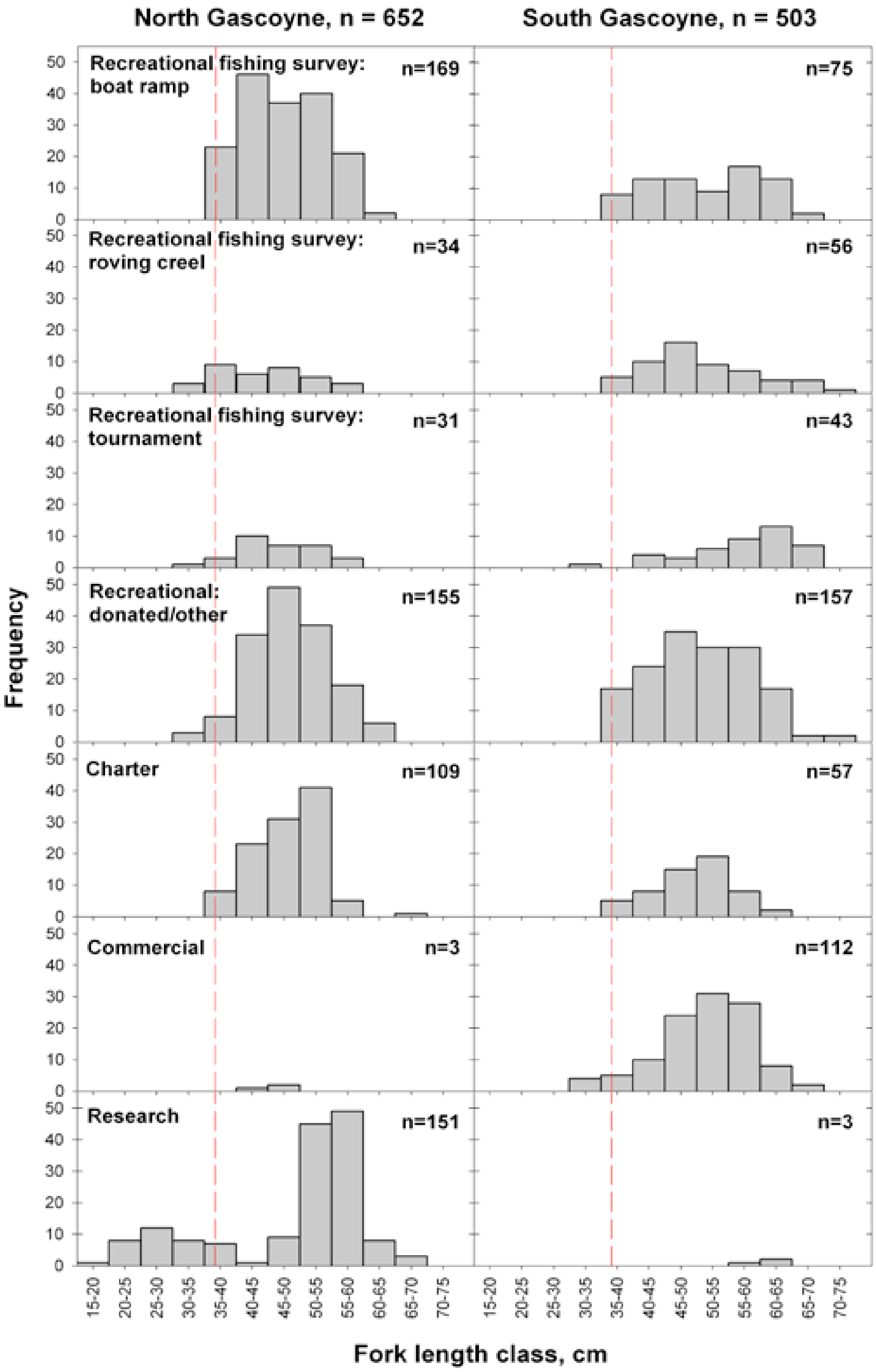



**Figure 5.2.3.** Length frequency distributions for spangled emperor sampled from different sources in 2007. Commercial data collected from 1 September 2006 to 31 August 2007, Recreational and Charter data collected from 1 April 2007 to 31 March 2008, Research data collected for 2007 calendar year. Vertical dashed lines show the FL equivalent (i.e. 36.68 cm FL) of the MLL (41cm TL).

The modal FL was larger for all samples collected from the South Gascoyne than from the North Gascoyne except for Donated/other recreational samples and Charter samples, where the modal lengths were the same between regions. Research specimens collected in the North Gascoyne had a bimodal distribution, associated with the collection of larger individuals from targeted sampling of suspected spawning aggregation sites and opportunistic sampling of smaller (< MLL) individuals from shallower waters for investigating suspected pre-maturational sex change and maturity of males and females (Marriott *et al*. 2010; Section 5.2.4). That the modal FL was largest for Research specimens sampled from suspected spawning aggregation sites than for all other samples from the North Gascoyne likely reflects a migration of predominantly large adults to these sampling sites during the spawning season.

Significant (non-trivial) variation was detected between RFS roving and Donated/other samples for North Gascoyne specimens but not for South Gascoyne specimens (Marriott *et al*. 2011a). Further, Marriott *et al.* (2011a) found that no detectable variation existed between RFS ramp and Donated/other samples for both North Gascoyne and South Gascoyne specimens, which indicated that it was valid to pool those samples at the level of Region (North Gascoyne, South Gascoyne) for subsequent analysis. This effectively validated the supplementation of samples that were considered to be representative of boat-based recreational catches for each region (i.e., the RFS ramp specimens; see Section 4.1.1) and these pooled data sets are referred to as the "representative" samples for spangled emperor catches herein.

The North Gascoyne representative catch at age distribution had a modal age of 5 years and the number of fish older than 6 years was relatively low (27.5% of displayed distribution) considering that the maximum observed age was 25.1 years for the North Gascoyne and 30.8 years for the Bioregion (Fig. 5.2.4.). The South Gascoyne representative catch at age distribution differed to the North Gascoyne distribution, demonstrating two strong modes at 4 and 6 years and a much higher proportion of fish sampled that were older than 6 years (56.5% of displayed distribution), out to a maximum age of 30.8 years (Fig. 5.2.4.). This observed difference in shape of age frequency distributions between regions was also statistically significant (Marriott *et al*. 2011a). Importantly, a higher number of older fish (> 15 years) were sampled from the South Gascoyne than from the North Gascoyne, despite a considerably lower sample size obtained for the South Gascoyne, indicating that this observed difference in the shape of the distributions was not likely attributable to sample size effects.

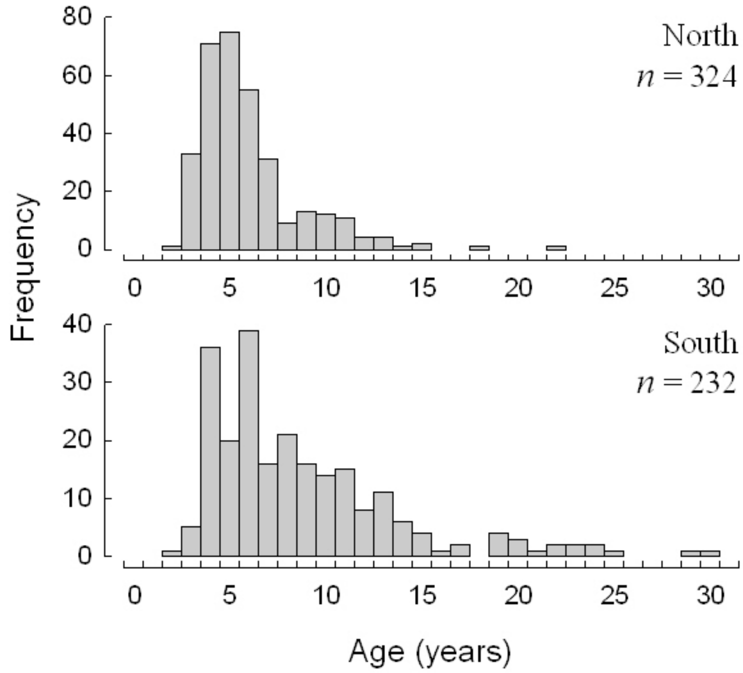



**Figure 5.2.4.** Representative catch at age distributions for spangled emperor landed recreational catches made in 2007/08 for North Gascoyne and South Gascoyne regions. Note the higher proportion of fish greater than 6 years of age in the South.

### 5.2.2.3.5 Growth

Marriott *et al.* (2011a) quantified the growth trend for male and female for spangled emperor in each assessment zone by fitting the von Bertalanffy growth model to length at age data. Parameter estimates and goodness of fit statistics from this work have been reproduced in Table 5.2.2. Marriott *et al.* (2011a) found that there was a significant difference in growth trends between zones but not between sexes. Growth in length was rapid from 0-5 yr, then the growth rate decreased to reach the average asymptotic length ($L_\infty$) at approximately 8-10 yr in the North Gascoyne and slightly older at 10-15+ yr in the South Gascoyne (Marriott *et al.* 2011a). The fitted curves also demonstrated a larger $L_\infty$ in the South Gascoyne than in the North Gascoyne (i.e., differed by ~7% of the South Gascoyne $L_\infty$; Marriott *et al*. 2011a). Estimates for the growth curvature parameter ($k$) indicated a relatively moderate growth rate (i.e., compared to other scalefish species) throughout life.

**Table 5.2.2.** von Bertalanffy growth parameters (± 95% CI) for female and male spangled emperor in the North, South, and for sexes combined.*
Reproduced from Marriott *et al.* (2011a).

| | $L_\infty$ (mm, FL) | $k$ (yr$^{-1}$) | $t_o$ (yr) | $A_{max}$ | $FL_{max}$ | $n$ | $r^2$ |
|---|---|---|---|---|---|---|---|
| North | | | | | | | |
| Female | | | | | | | |
| Estimate | 591.5 | 0.254 | -0.244 | 20.9 | 671 | 505 | 0.84 |
| Upper | 605.1 | 0.277 | -0.041 | | | | |
| Lower | 578.0 | 0.230 | -0.447 | | | | |
| Male | | | | | | | |
| Estimate | 556.3 | 0.318 | 0.064 | 25.1 | 650 | 507 | 0.68 |
| Upper | 567.0 | 0.354 | 0.417 | | | | |
| Lower | 545.6 | 0.281 | -0.288 | | | | |
| South | | | | | | | |
| Female | | | | | | | |
| Estimate | 623.7 | 0.177 | -1.68 | 27.8 | 707 | 365 | 0.61 |
| Upper | 643.3 | 0.215 | -0.43 | | | | |
| Lower | 604.1 | 0.138 | -2.93 | | | | |
| Male | | | | | | | |
| Estimate | 604.8 | 0.182 | -1.61 | 30.8 | 677 | 299 | 0.65 |
| Upper | 624.2 | 0.221 | -0.41 | | | | |
| Lower | 585.4 | 0.142 | -2.81 | | | | |
| Sexes combined | | | | | | | |
| North | | | | | | | |
| Estimate | 573.1 | 0.282 | -0.133 | 25.1 | 671 | 1012 | 0.79 |
| Upper | 581.5 | 0.300 | -0.297 | | | | |
| Lower | 564.8 | 0.263 | 0.031 | | | | |
| South | | | | | | | |
| Estimate | 616.0 | 0.179 | -1.60 | 30.8 | 707 | 664 | 0.63 |
| Upper | 629.9 | 0.207 | -0.74 | | | | |
| Lower | 602.1 | 0.152 | -2.46 | | | | |

#### 5.2.2.3.6 Natural mortality

The coefficient describing the instantaneous rate of natural mortality ($M$) was estimated for the for spangled emperor Gascoyne stock by Marriott *et al.* (2011a) using a range of different methods (Moran *et al.* 1993; Hoenig 1983; Hewitt *et al.* 2007). They determined a biologically plausible estimate for $M$ = 0.146 year$^{-1}$, which was a consistent estimate produced from: (i) fitting a catch curve to age structure data from a lightly exploited population and (ii) applying the maximum estimated age from the bioregion (30.75 yr) to the formula of Hoenig (1983) (Marriott *et al.* 2011a).

* $L_\infty$ hypothetical asymptotic length at infinite age, FL, fork length, $k$, growth coefficient, $t_o$, hypothetical age at zero length, $A_{max}$, maximum age, $FL_{max}$, maximum fork length, $n$, sample size, $r^2$, coefficient of determination.

### 5.2.2.4 Discussion

A relatively low frequency of spangled emperor sampled older than 6 years in the North Gascoyne in 2007/08 is consistent with impacts of fishing on the population age structure in that region. An independent comparison of the 2007/08 North Gascoyne age distribution with an age distribution sampled from the North West Cape (within the North Gascoyne region) in 1989-91 provided evidence to suggest that there has been depletion of older for spangled emperor in the North Gascoyne population since 1989-91 (Marriott *et al.* 2011a). There was a statistically significant difference detected between these North Gascoyne age frequency distributions, due to a much smaller proportion of spangled emperor that were older than 6 years in 2007/08 (27.5%) than in 1989-91 (50.3%; Marriott *et al.* 2011a).

Fewer older fish will remain in populations exposed to fishing mortality because older fish have typically been exposed to mortality for longer periods than younger fish and are therefore numerically less abundant in fish populations prior to fishing (Cushing 1968). Assuming that the presented age distributions were accurately representative of population age structure (past the modal age) and that there was no influence of other factors, such as highly variable recruitment, consistent with the assumptions of conventional catch-curve analyses (Beverton and Holt 1957; Ricker 1975). Catch curve analyses of these datasets were done by Marriott *et al.* (2011a) and are reported as part of the 'weight of evidence assessments' presented in Section 6.3.3.2.

### 5.2.3 Recruitment

Larvae of spangled emperor were found to hatch from fertilised ova approximately 24 hours post-spawning (Arvedlund and Takemura 2006). Larvae remain in the water column for approximately 45 days until they metamorphose and settle in shallow seagrass beds as juvenile fish (Ebisawa 1990; Arvedlund and Takemura 2006). Arvedlund and Takemura (2006) found that juveniles use well-developed olfactory organs to select their first benthic habitat based on chemical cues emitted by these seagrass bed nursery ground habitats. Their research indicated that juveniles also probably select their benthic habitat (seagrass beds) at night, as do many other species of coral reef fishes (e.g., Kingsford 2001).

There have been no studies into recruitment variability for this species although Moran *et al.* (1993) inferred that the multi-modal age frequency distribution for for spangled emperor sampled from the Abrolhos Islands, at the southern end of this species' range in WA, could be a manifestation of infrequent and variable strength of larval supply to that area from spawning events further north. D'Adamo and Simpson (2001) suggested that the Ningaloo Reef system might act as a source of eggs and larvae to reefs in the Monte Bello Islands and Dampier Archipelago during summer, when the north-flowing Ningaloo Current facilitates larval transport. The spring/ summer spawning pattern demonstrated for Gascoyne populations by Moran et al. (1993) (and in Section 5.2.4 below) is consistent with this latter view for larval dispersal. Recently, Berry *et al.* (2012) postulated that both larval cohesion and extremely limited juvenile dispersal prior to maturity could explain an observed decreasing genetic autocorrelation with age detected at fine spatial scales in the Bioregion. Hydrodynamic modelling showed that larvae were likely to be transported hundreds of kilometres, which supported their findings (Berry *et al.* 2012).

### 5.2.4 Reproduction

#### 5.2.4.1 Introduction

The reproductive development of spangled emperor has previously been investigated in Japan (Ebisawa 1990), the North-West Shelf and Gulf of Carpentaria in northern Australia (Young and Martin 1982), north Western Australia including Ningaloo Marine Park (MP) (Moran *et al.* 1993), the Great Barrier Reef (Grandcourt 1999) and Egypt (Salem 1999). Results on the mode of sexual ontogeny have differed, with gonochorism (no sex change) inferred from analysis of sex-specific size frequency and limited histology (Young and Martin 1982; Salem 1999) to inferred pre-maturational (i.e., non-functional *sensu* Sadovy de Mitcheson and Liu 2008) protogyny (female to male sex change) from histological analysis of a broader size range of individuals (Ebisawa 1990; Grandcourt 1999). Moran *et al.* (1993) previously analysed sex-specific size frequency in the Ningaloo MP but failed to demonstrate any evidence of sex change.

Marriott *et al*. (2010) recently used accurate histological methods to describe in detail the sexual and reproductive development of spangled emperor in the North Gascoyne study region (Zones 5 to 7 combined) and identified a non-functional, pre-maturational protogynous development. It was not possible to investigate maturation and sexual ontogeny in the South Gascoyne (Zones 1 to 4 combined) using those methods because sampling efforts for specimens under the MLL (and therefore immature and sex-changing fish) in that region were unsuccessful. Marriott *et al.* (2010) demonstrated that all of the smallest and youngest fish sampled were female until they either changed sex to male at a mean length of 27.8 cm TL and age of 2.3 years or remained female and matured at a larger mean length of 39.2 cm TL and older age of 3.5 years. Importantly, that study demonstrated that both pre-maturational sex change and average female maturity occurred at sizes smaller than the current MLL. This indicates that at least half of all females can spawn at least once prior to growing to the MLL and that sex change (contributing to biased sex ratios) does not occur within the legally permissible size range for retained catches.

Spawning in spangled emperor populations has been studied in East Africa (Nzoika 1979), New Caledonia (Loubens 1980), Japan (Ebisawa 1990), north Western Australia (Moran *et al.* 1993), Egypt (Salem 1999) and the southern Arabian Gulf (Grandcourt *et al.* 2010). In North-Western Australia, Moran et al. (1993) found evidence for peak spawning from October 1989 to February 1990 and from November 1990 to March 1991 from analysis of monthly trends in relative gonad weights, with spawning in the Mid-West area (Abrolhos Islands) occurring a month or two later than in the North-West area (North West Cape, North West Shelf). Changes in mean egg diameters and mean gonad index with fish length during the spawning season were used by Moran *et al.* (1993) to infer the average length at maturity of 380 mm FL for North-Western Australian populations, which was used to revise the MLL from 28 cm to 41 cm TL in 1994. Fecundity estimates for spangled emperor were made by Ebisawa (1990) and Salem (1999), which involved counts of oocytes larger than 120 μm and 320 μm respectively, but since these counts included smaller (and less developed) oocyte stages than hydrated oocytes, they likely over-estimated batch fecundity for this species (Hunter *et al*. 1985).

Spangled emperor are known to form spawning aggregations throughout their circum-tropical distribution (Salem, 1999; Grandcourt *et al.* 2010). Salem (1999) described a spawning aggregation site for spangled emperor at Jackfish Alley, off the Sinai Peninsula in the Red Sea, which was commercially fished, with highest catch rates observed over a 10-12 day period either side of the full moon. Spawning occurred over two successive lunar cycles, with peak spawning activity reported on the third day following the full moon. Grandcourt *et al.* (2010) also reported peak spawning activity for spangled emperor occurring shortly after the full moon in the Southern Arabian Gulf. It is possible that spangled emperor may travel large distances to aggregation sites and be vulnerable to fishing when in aggregations during the spawning period.

Off Ningaloo Reef, field observations have identified high catch rates of relatively large spangled emperor from aggregations during October and November, although histological examination of sampled ovaries did not verify the females as being in the act of spawning (DoFWA, unpublished data). Also, some recent acoustic tracking work showed that, during the spawning season, one spangled emperor individual moved outside of the lagoon and proximity of the network of receiver stations in Mangrove Bay in October 2008 to a suspected spawning aggregation site, only to return back to that lagoon in mid-December that year, towards the end of the spawning period (R. Pillans, unpublished data). Further, some individuals were tagged at a suspected spawning aggregation site, left the site, and were observed to return nearby during the same lunar phase the following year (R. Pillans, unpublished data). These observations suggest that the spatial distribution of spangled emperor may alter during the spawning season due to the migration of adult spawners to spawning aggregation sites.

The spawning season of spangled emperor is reported here for the two study regions assessed for this report: South Gascoyne (Zones 1 to 4 combined) and North Gascoyne (Zones 5 to 7 combined). In addition, given the aforementioned methodological issues with published estimates of batch fecundity, a preliminary estimate of batch fecundity for spangled emperor is presented here, as it will be used in the egg per-recruit assessment in Section 6.3.

#### 5.2.4.2 Methods

Sex was determined and maturity stages were estimated from ovaries and testes using macroscopic and histological techniques according to methods outlined in Sections 4.1 and 4.2 and reported in Marriott *et al*. (2010). Seasonal spawning patterns were assessed by analysing trends in the mean monthly gonado-somatic index (GSI) values, where GSIs were calculated as the gonad weight (GW: g) divided by the total body weight (BW: g) for each specimen. In instances where BW data were not available, BW was estimated from FL measurements (mm) according to the following formula: $BW = 6.002 \times 10^{-5} FL^{2.810}$ generated from fitting the power function to observed BW on FL data ($n = 204$; $r^2 = 0.975$). Overlayed on this plot were the monthly proportions of ovaries sampled that were macroscopically staged as either Developed (Stage 4) or Spawning (Stage 5), for assessing seasonal patterns in reproduction. These stages were grouped together as the "Ripe" category for males and females. Batch fecundity estimates were made from counts of only the whole hydrated oocytes identified in samples (wedges) of ovarian lamellae extracted from a small number of preserved ovary specimens ($n = 8$) using the gravimetric method of Hunter et al. (1985) (see Section 4.2.2).

#### 5.2.4.3 Results

Plots of monthly GSI and proportion ripe ovaries and testes demonstrate similar patterns in the timing of reproduction for females and males in both Gascoyne regions, with peak reproduction occurring from September to November each year (Fig. 5.2.5.). There were conspicuously fewer data collected from the South Gascoyne, which meant that trends for that region were presented with less precision. A paucity of specimens shown for the South Gascoyne post-April 2008 reflects a marked reduction in sampling in that region due to the completion of the Recreational Fishing Survey (RFS) in March 2008. Specimens collected post-April 2008 were those obtained from regular sampling in the North Gascoyne and infrequent sampling at fishing tournaments in the South Gascoyne for the NRM Rangelands funded project, "Implementing a Research Angler Program in the Gascoyne".

A repeated-measures ANOVA revealed no significant effect of wedge (preserved lamellae sample) position (Anterior, Medial, Posterior) within ovaries on the number of hydrated oocytes counted per gram wedge weight ($F_{2,14} = 1.09$, $P = 0.36$), indicating that it was valid to average oocyte counts across the three ovarian wedge weights for estimates of batch fecundity (BF) for each fish (Table 5.2.3.). There was no clear trend in BF with FL, whole weight or estimated age.

The average BF per gram of body weight from these data was $\overline{X}_{fec/g} = 41.18 \pm 16.25$ s.e. eggs.

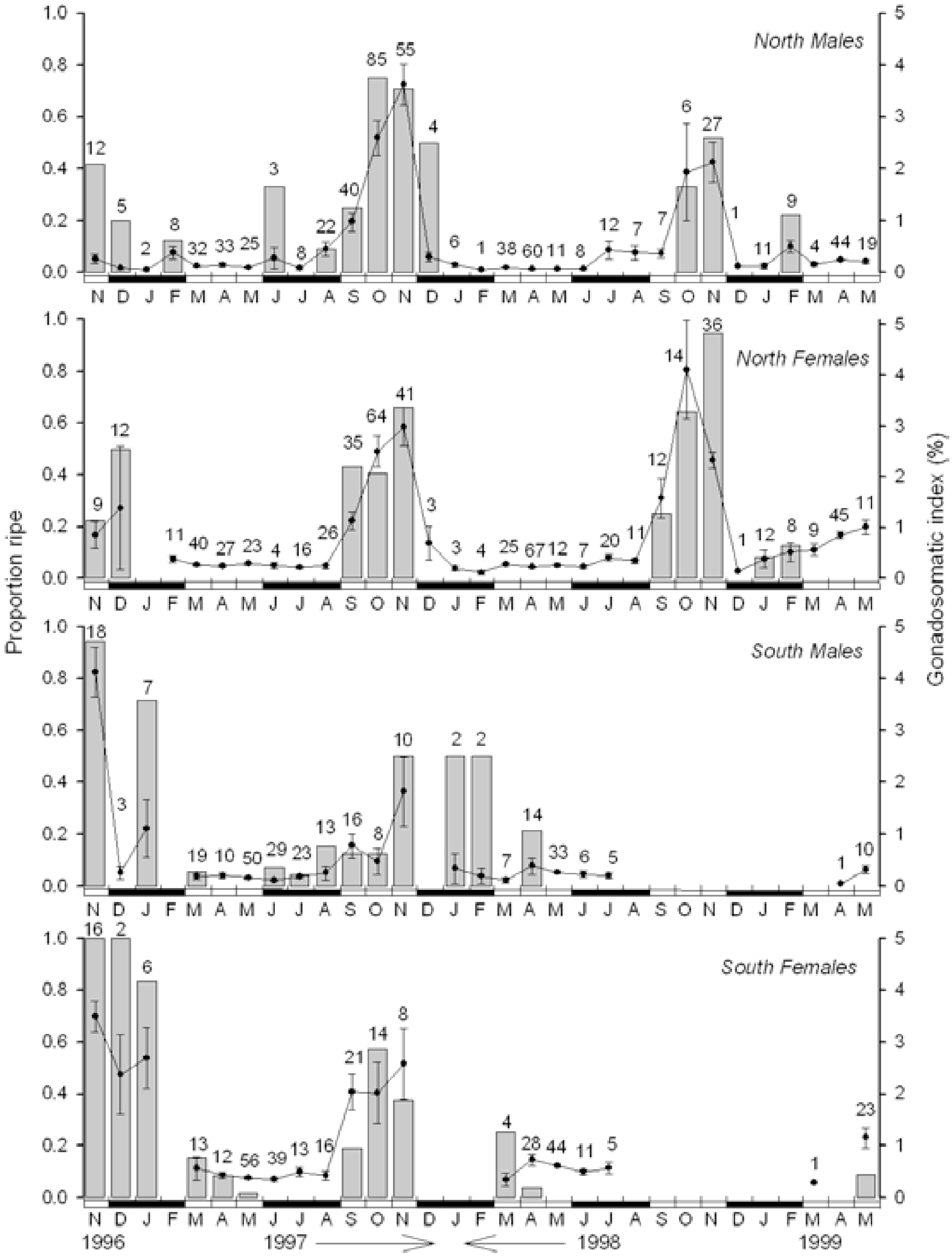



**Figure 5.2.5.** Mean monthly gonadosomatic indices (±1 SE, solid lines, sample sizes above) and percentage of macroscopic stages 4 and 5 (Ripe) combined (grey bars) for females and males of spangled emperor from the North (above) and South (below) Gascoyne assessment regions.

**Table 5.2.3.** Batch fecundity estimates for spangled emperor.

| Fish Identifier | Ovary weight (g) | FL (mm) | Age (yr) | BF (eggs) | CV |
|---|---|---|---|---|---|
| SE060902-18 | 79.88 | 499 | 8.92 | 243,397.63 | 0.032 |
| SE060902-20 | 70.10 | 510 | 15.92 | 26,177.87 | 0.599 |
| SE060902-3 | 137.60 | 557 | 14.92 | 271,267.70 | 0.140 |
| SE061126-123 | 93.50 | 640 | 12.08 | 14,522.23 | 0.087 |
| SE061126-133 | 110.07 | 595 | 9.08 | 94,982.47 | 0.071 |
| SE070131-1 | 149.58 | 551 | 9.25 | 8,412.51 | 0.116 |
| SE070131-5 | 86.16 | 600 | 10.25 | 3,111.52 | 0.564 |
| SE071113-1 | 70.98 | 520 | 15.08 | 239,921.86 | 0.018 |

#### 5.2.4.4 Discussion

That peak spawning activity occurs outside of the peak period for recreational fishing (winter) suggests that spawning aggregations of spangled emperor are presently less susceptible to potential impacts of targeted recreational fishing than they could be. Sumner *et al.* (2002) demonstrated that recreational fishing activity diminished from October to March when inclement weather and sea conditions restricted boating and high temperatures in the Gascoyne were less appealing to visiting tourists. Departmental research is continuing on the fine-scale spawning parameters of spangled emperor populations, including spawning fractions over the lunar cycle and supplementing sample sizes for improved estimates of batch fecundity, in order to provide a better understanding of spawning stock dynamics for future stock assessments and management.

### 5.2.5 Other factors influencing susceptibility to exploitation

Data from voluntary Research Angler Program (RAP) logbook users fishing in the Gascoyne bioregion to April 2009 showed that the majority of spangled emperor caught by these fishers (76%) were released (n = 263). The main reasons for releasing spangled emperor were that anglers either preferred to release them (53%) and because they were below the MLL (410 mm TL; 47%). Preliminary analyses of these data indicated no obvious trend of release rates with increasing depth or length above MLL, although the highest number of catches were from relatively shallow (< 5 m) waters.

Relatively high post-release survival rates observed from tag-recapture (Moran *et al.* 1993) and acoustic monitoring (Chateau and Wantiez 2008; R. Babcock unpublished data) studies demonstrate that spangled emperor have relatively low probability of post-release mortality when caught from shallow depths (< 10 m) and handled in a way that minimises fish stress (e.g., see Code of Conduct for Recreational Fishing on Department of Fisheries WA website, www.fish.wa.gov.au). Given that a high proportion of spangled emperor caught are released, post-release survival is a key consideration in the future sustainable harvest of this species. Importantly, post-release survival of spangled emperor caught in deeper depths is unknown, but is likely to be markedly lower than from captures in shallower depths (e.g., Rogers *et al*. 1986; Wilson and Burns 1996; Lenanton *et al.* 2009b).

## 5.3 Goldband snapper

### 5.3.1 Distribution, structure and movement

Goldband snapper are widely distributed throughout the tropical Indo-Pacific from Samoa to the Red Sea and from southern Japan to Australia (Allen 1985). In Western Australia, goldband snapper are found from Cape Pasley (east of Esperance) northwards (Newman and Dunk 2003) at depths of 60 – 250+ m. In the Gascoyne Coast Bioregion, goldband snapper are mostly caught by commercial fishing in waters of 150-250 m depth.

The stock structure of goldband snapper has previously been investigated for Kimberley, Northern Territory and Indonesian populations (Lloyd *et al*. 1996; Newman *et al*. 2000; Ovenden *et al*. 2002; Ovenden *et al.* 2004). In Indonesia, genetic subdivision was apparent over relatively small spatial scales (< 500 km), suggesting that all life stages of this species may be relatively sedentary (Ovenden *et al.* 2004). In Australia, goldband snapper stocks in the Kimberley and Northern Territory were found to be genetically distinct while otolith chemistry analysis indicated that adults remained sedentary on individual reefs (Lloyd *et al.* 1996; Newman *et al*. 2000; Ovenden *et al.* 2002).

### 5.3.2 Age and growth

#### 5.3.2.1 Introduction

Age and growth of goldband snapper have been previously studied in Papua New Guinea (Richards 1987), the Timor Sea (Edwards 1985), Malaysia (Mohsin and Ambak 1996), and off the Kimberley coast of Western Australia (Newman and Dunk 2003). The results of these studies have varied largely due to the different methods used to determine age. Using transverse otolith sections and validation with edge-type analysis Newman and Dunk (2003) produced estimates of age up to 30 years. Results of this study showed Kimberley fish to be long-lived and relatively slow growing with no significant difference in growth between the sexes.

#### 5.3.2.2 Methods

Goldband snapper were sampled using fishery-dependent and fishery-independent methods, sex was determined and ages were estimated according to methods outlined in Chapter 4.0. Data were analysed for the area south of Point Maude only (South Gascoyne).

Estimates of fish age (in years) were obtained based on counts of opaque zones observed in transverse otolith sections as described in Section 4.0. Recently deposited material on the proximal otolith margin (growing surface) was categorised as either ‘wide translucent’, ‘narrow translucent’ or ‘opaque’, consistent with the categories of Marriott *et al*. (2010). The monthly proportions of each otolith edge-type were plotted for a 13-month period of sample collection, from 1 November 2007 to 30 November 2008, in order to describe trends in opaque increment deposition in goldband snapper otoliths from the Gascoyne. The patterns in timing and periodicity of opaque increment deposition were used to validate the ageing methods for goldband snapper from the Gascoyne (see Section 5.3.2.3.3).

Age compositions of females and males were compared using histograms with the data pooled across all collection methods, sectors and sampling years. Growth was modelled by fitting von Bertalanffy growth curves to length (FL, mm) at age (*t,* years) data,

$$\mathrm{FL} = L_{\infty}(1 - e^{-K(t-t_0)})$$

Initial fits of the model resulted in relatively large departures of $\hat{t}_0$ from zero due to the absence of fish younger than 4 years in the samples. Therefore, the von Bertalanffy growth curve was fitted with a biologically sensible constraint on $t_0$, which was a fixed value of zero (Marriott *et al*. 2007). Prior to fitting the growth curves separately to data for each sex, length-at-age data were compared by linearly transforming these data and then testing for significant differences in slope and elevation using ANCOVA. Sex-specific fits of the von Bertalanffy growth model were then tested for significant difference to the fit to pooled data using the coincident likelihood ratio test of Cerrato (1990) as a check to the former analysis.

### 5.3.2.3 Results

#### 5.3.2.3.1 Contribution of samples from each sector

Samples were obtained via fishery-dependent sampling of commercial catches taken by SBSF vessels and from fishery-independent research sampling (Table 5.3.1.). All data in Table 5.3.1 are presented by Calendar year for comparison, in addition to the relevant sampling "years" used in / considered for analyses, which are in normal font type (see Section 4.4 for details).

**Table 5.3.1.** Numbers of goldband snapper obtained from the Gascoyne Coast Bioregion.

| Sector | | Year | | | | | % |
|---|---|---|---|---|---|---|---|
| | Year type | 1 | 2 | 3 | 4 | 5 | |
| Commercial | Commercial | 124 | 140 | 242 | 17 | 401 | 74 |
| | Calendar | 124 | 262 | 120 | 223 | 310 | |
| Research | Calendar | | 331 | | 42 | | 26 |
| Total | | 124 | 593 | 120 | 265 | 310 | 1412 |

| Year type | Start Date | End Date | Common months | Year | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 |
| Calendar | 1 Jan | 31 Dec | Apr - Aug | 2004 | 2005 | 2006 | 2007 | 2008 |
| Commercial | 1 Sep | 31 Aug | Apr - Aug | 2003/04 | 2004/05 | 2005/06 | 2006/07 | 2007/08 |

Although good numbers were obtained from research sampling in the 2005 calendar year, research sampling was not considered useful for providing an accurate representation of population age structure past the modal age for that year. Therefore, only the 2007/08 commercial catch-at-age data were adequate for assessing population age structure, as determined according to the criteria of Craine *et al.* (2009) (Table 5.3.2.). The 2005/06 commercial sample was just outside of the acceptable range of sampling precision (i.e. 0.04 – 0.08; Craine *et al.* 2009), so this dataset was also analysed to assess population age structure, although the results for the 2005/06 commercial sample should be treated with caution, accordingly. In this context, the reported precision values represent how well a sampled age frequency distribution will reflect the shape of the population age frequency distribution from which it was sampled, in the absence of sampling bias, and was derived using the Kolmogorov-Smirnov $D$ statistic as explained in Craine *et al.* (2009).

**Table 5.3.2.** Calculated precision values for commercial age samples of goldband snapper by year of sample collection according to the method of Craine *et al.* (2009) (Commercial fishing year: 1 September to 31 August).

| Year | Collection period | Number | Precision | OK? |
|---|---|---|---|---|
| 2003/04 | April 2004 – August 2004 | 124 | 0.122 | ☒ |
| 2004/05 | March 2005 – August 2005 | 140 | 0.115 | ☒ |
| 2005/06 | September 2005 – April 2006 | 242 | 0.087 | ☑ |
| 2006/07 | April 2007 | 17 | 0.513 | ☒ |
| 2007/08 | November 2007 – August 2008 | 401 | 0.068 | ☑ |

### 5.3.2.3.2 *Bias and precision*

Agreement among opaque zones counts between readers was high, with 68.1% of counts identical and never different by more than two zones. Differences in opaque zone counts between readers of 1 and 2 zones occurred for 30.7% and 1.2%, of readings, respectively. No significant or consistent trend in drift or bias was evident from the age bias plot (Fig. 5.3.1.). The IAPE value was very low at 1.45%, well within the acceptable levels recommended by Campana (2001) for species with intermediate (10-30 years) to long (> 30 years) life spans with otoliths of moderate reading complexity.

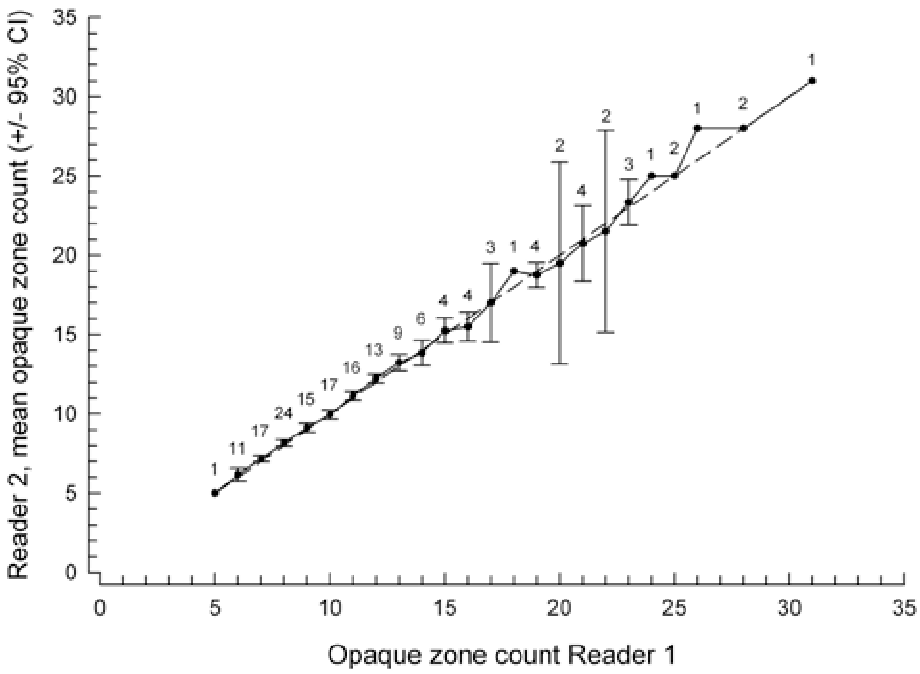



**Figure 5.3.1.** Age bias plot for repeated readings of goldband snapper done by primary age reader (n = 163). IAPE = 1.45%. Numbers above points are sample sizes

### 5.3.2.3.3 *Validation*

Edge-type analysis has previously been used to 'validate' fish age with goldband snapper populations in the Kimberley region of WA (Newman and Dunk 2003). A similar approach was used here and indicated an approximately annual pattern in opaque and translucent increment formation in goldband snapper otoliths from the Gascoyne (Fig. 5.3.2.).

Otoliths with opaque margins were sampled in high proportions in November-December 2007 and declined in March 2008 then increased steadily to a peak of ca. 88% in August 2008 before starting to decline again. An observed decline in the monthly proportions of opaque increments coincided with an initial peak in otoliths with narrow translucent margins in March 2008, followed by a peak in otoliths with wide translucent margins in April 2008. Note, however, that the absence of otoliths collected for some months weakens conclusions from this analysis, although it corroborates the finding from the more comprehensive analysis of Newman and Dunk (2003) using specimens collected from the Kimberley, that opaque increments are deposited on an approximately annual basis in otoliths of goldband snapper.

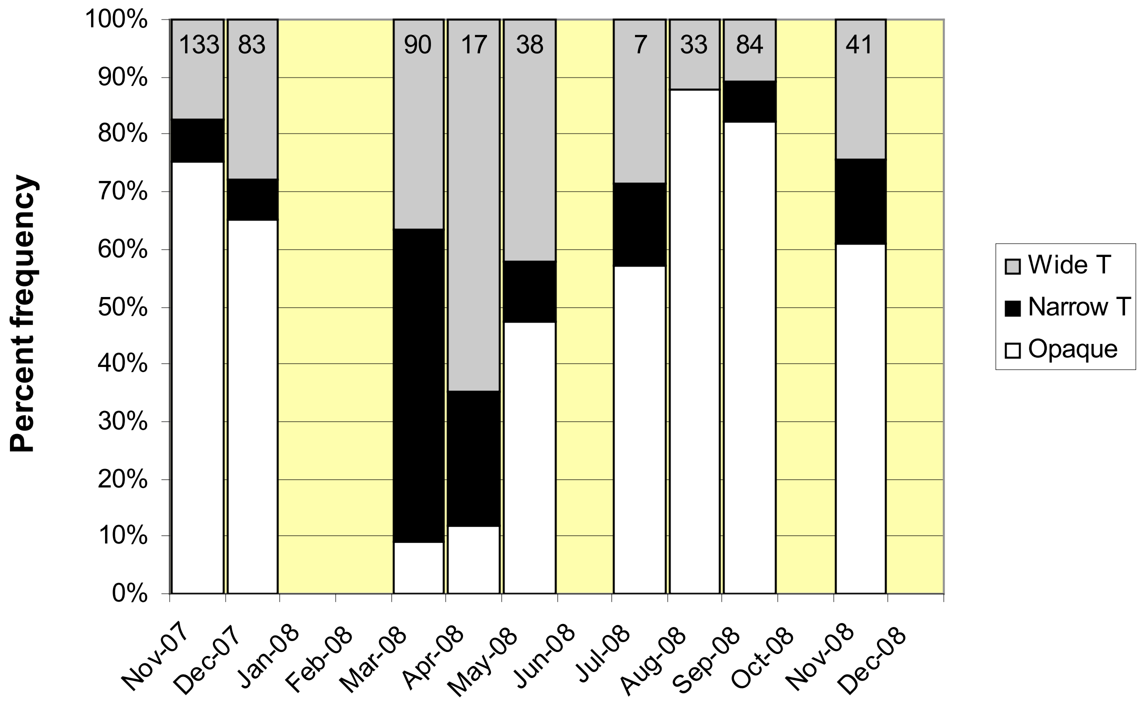



**Figure 5.3.2.** Edge-type analysis of goldband snapper otolith sections from samples collected in the South Gascoyne 2007-2008. Numbers represent monthly sample sizes.

### 5.3.2.3.4 Length and age composition of stock

Length frequency distributions using data for all specimens for which length and sex information was available demonstrated that a higher proportion of fish in the largest length groups were female, with the overall sampled sex ratio slightly male-biased 1M: 0.84F (Fig. 5.3.3.).

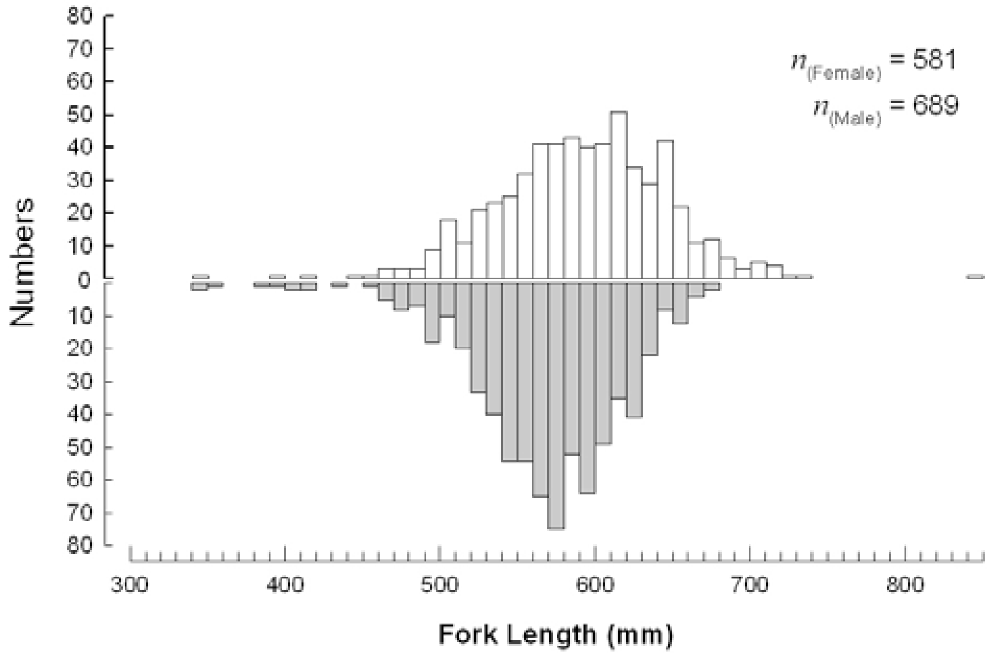



**Figure 5.3.3.** Length frequency distributions for female (white bars, above x-axis) and male (grey bars, below x-axis) goldband snapper from the South Gascoyne.

After meeting an acceptable level of sampling precision based on sample size (Table 5.3.2) and assuming that samples were collected in a manner that provided an accurate representation of population age structure past the modal age (refer Section 4.1.1), commercial age samples for the 2005/06 and 2007/08 Commercial years were treated as "representative" samples for subsequent analyses. Inspection of the representative age distributions for the 2005/06 and 2007/08 commercial samples demonstrated that fish were sampled from almost all age classes past the modal age, up to a maximum observed age class of 30 years (Fig. 5.3.4.). The modal age of both distributions was relatively old, at 7 years for the 2005/06 sample and was bimodal for the 2007/08 sample at 8 and 10 years, with no goldband snapper sampled younger than 4 years. In the absence of any MLL for this species, this suggests that many young goldband snapper are not selected or available (or both) to commercial line fishing gear and operations.

Although it is possible that some of the observed variability in these catch-at-age distributions might have reflected recruitment variability among the sampled cohorts, there was little evidence to suggest this in the presented data. For instance, the second strong mode in the 2007/08 age structure at 10 years did not reflect any obviously elevated frequency at 8 years in the 2005/06 age structure. Further, although a cursory examination of all commercial catch-at-age data collected from 2003/04 to 2007/08 did reveal variable age frequency distributions from year to year, no consistent modal progression of recruitment pulses through successive annual samples was evident.

The apparent lack of modal progression across these two distributions could reflect either an imprecision or biases in sampling, imprecise or inaccurate age estimations, that the samples could contain fish from multiple stocks, or a combination of these. As previously stated, the age estimation method has been demonstrated to produce both accurate and precise results in this instance. It is possible that sampling imprecision or bias might have resulted in some variability not related to true variability in the population age structure of the stock. For instance, fishery-dependent sampling of the landed catches might have been susceptible to variation attributable to size-dependent grading or other fishery- or market-based influences, on top of the variation attributable to the underlying fish population dynamics. As for underlying stock structure, it is not known whether there is a finer-scale structuring to the fished goldband snapper stock in the Gascoyne Bioregion, although elsewhere this species is known to demonstrate genetic structuring over relatively fine spatial scales (see Section 5.3.1).

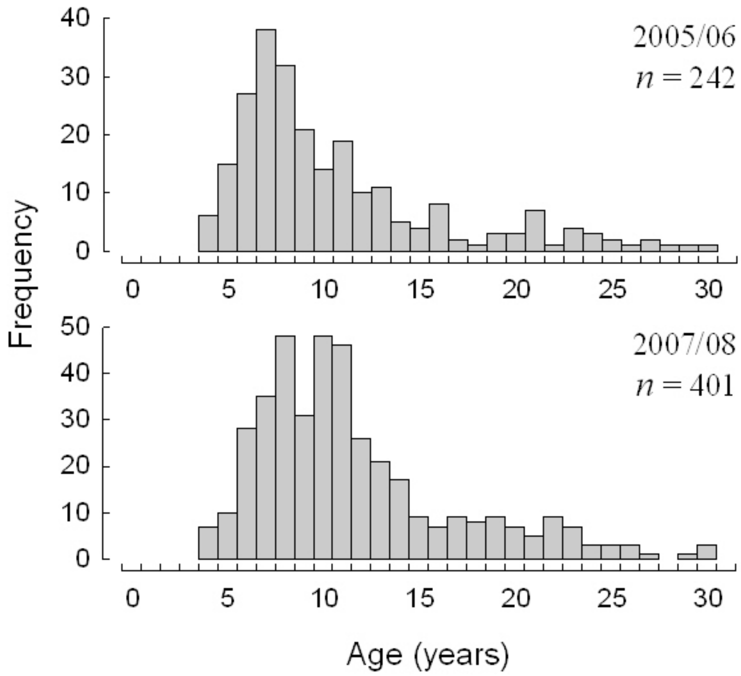



**Figure 5.3.4.** Age frequency distributions of goldband snapper from the South Gascoyne in 2005/06 and 2007/08.

### 5.3.2.3.5 Growth

The von Bertalanffy growth equations fitted to length at age data showed relatively rapid growth during the first 5 years of life for both sexes. Thereafter, growth slowed prior to reaching the asymptotic length, with little variation in the mean growth rate after approximately 10 years of age. The maximum estimated age was 30+ years for both sexes (Table 5.3.3). The fitted von Bertalanffy growth models did not, however, explain plotted length at age data well, in terms of $r^2$, probably because of the absence of fish less than 5 years or age, where most of the increase in length at age would have occurred (Table 5.3.3.; Fig 5.3.5.).

Despite a large overlap in length at age data for most of the sampled length range, females appeared to be larger, on average, than males for age classes older than 20 years (Fig. 5.3.5.) and the fit of the growth model to data for different sexes was significantly different (log-likelihood = 39.73, test statistic = 7.82, $p < 0.05$). A significantly steeper slope detected by the ANCOVA for female linear-transformed length at age data ($F_{1,963} = 10.27$, $p = 0.001$) reflected a departure in the average lengths sampled for older age classes, where females were observed to be larger, for a given age, than males. This was quantified as a larger $\hat{L}_\infty$ for females than for males, despite a similar $\hat{K}$ between sexes (Table 5.3.3.). This average difference, however, was relatively minor, being only 27.6 mm between the constrained model fits (15.9 mm between unconstrained fits), which was a small percentage of its average asymptotic length (4.4% and 2.5%, respectively).

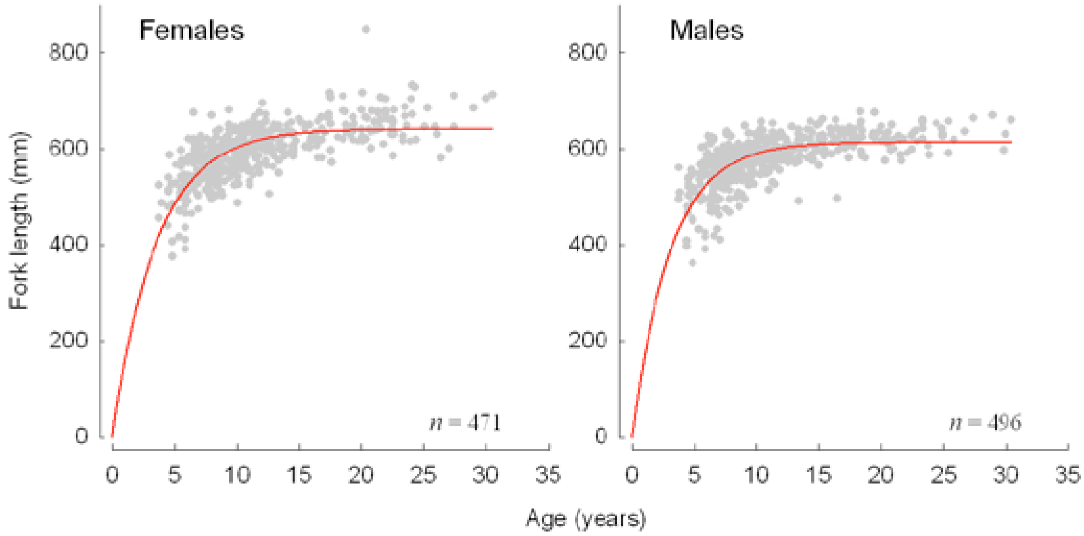



**Figure 5.3.5.** Constrained ($t_0$=0) von Bertalanffy growth model fitted separately to length at age data for male and female goldband snapper.

**Table 5.3.3.** von Bertalanffy growth parameters (± 95% CI) for goldband snapper in the Gascoyne region.

| | $L_\infty$ (mm, FL) | $k$ ($yr^{-1}$) | $t_o$ (yr) | $A_{max}$ | $FL_{max}$ | $n$ | $r^2$ |
|---|---|---|---|---|---|---|---|
| Female | | | | | | | |
| Estimate | 640.4 | 0.283 | 0* | 30.50 | 846 | 472 | 0.51 |
| Upper | 647.0 | 0.297 | n/a | | | | |
| Lower | 634.8 | 0.269 | n/a | | | | |
| Male | | | | | | | |
| Estimate | 612.8 | 0.327 | 0* | 30.42 | 676 | 499 | 0.45 |
| Upper | 618.5 | 0.344 | n/a | | | | |
| Lower | 607.0 | 0.310 | n/a | | | | |
| Sexes combined | | | | | | | |
| Estimate | 626.9 | 0.302 | 0* | 30.50 | 846 | 971 | 0.47 |
| Upper | 631.4 | 0.313 | n/a | | | | |
| Lower | 622.5 | 0.291 | n/a | | | | |

$L_\infty$ hypothetical asymptotic length at infinite age, FL, fork length, $k$, growth coefficient, $t_o$, hypothetical age at zero length (not estimated for this species), $A_{max}$, maximum age, $FL_{max}$, maximum fork length, $n$, sample size, $r^2$, coefficient of determination. * = fixed at zero (not estimated from data).

#### 5.3.2.3.6 Natural mortality

Given that the maximum estimated age for goldband snapper of 30 yr in the Gascoyne is consistent with that observed in the Kimberley, the coefficient describing the instantaneous rate of natural mortality ($M$) was assumed to approximate the value previously published for the Kimberley as being within the range of $M$ = 0.104-0.139 (Newman and Dunk 2003). This assumption is consistent with the general finding of Hoenig (1983) that longevity is inversely proportional to natural mortality on a log-scale (i.e., so $M$ can be predicted from maximum age).

### 5.3.2.4 Discussion

The longevity of goldband snapper from the Gascoyne (maximum age ca. 30+ years) is similar to that found with goldband snapper in the Kimberley (Newman and Dunk 2003). Edge-type analysis of available otolith samples collected from November 2007 to November 2008 indicated an approximately annual pattern, supporting the accuracy of these age estimates from the Gascoyne.

The length-at-age data that were available only represented goldband snapper growth after 4-5 years of age for males and females as younger fish were not represented in the samples. As a result, a biologically sensible constraint (i.e. $t_0 = 0$) was applied to the von Bertalanffy model to describe mean growth rates. Despite overlap observed in the length-at-age data collected for different sexes, the fitted models demonstrated significantly different growth trends between sexes. However, although the fit of the von Bertalanffy growth model to data for separate sexes demonstrated a larger average length for females than males in the oldest age classes, the difference in fitted maximum asymptotic fork length ( $\hat{L}_\infty$ ) values was relatively small (<5%).

There were other differences evident between the growth results observed here for Gascoyne populations and those reported by Newman and Dunk (2003) for Kimberley populations. The growth curvature parameter estimated in the Kimberley study ( $\hat{K}$ = 0.1873; Newman and Dunk, 2003) was lower than that estimated in this study, although this difference might be explained, at least in part, due to different methods of fitting the growth model between studies. The relatively low number of specimens sampled younger than 5 years old and the necessary constraint on $t_0$ for fitting the von Bertalanffy model to these data was likely to have influenced $K$ estimates for the Gascoyne as a result of parameter correlation effects (Bernard 1981).

Interestingly, $L_\infty$ estimates in this study were 37.1 mm larger (60.7 mm larger for unconstrained fit) for females and 18.3 mm larger (35.1 mm larger for unconstrained fit) for males than reported for the Kimberley stock. Also, the significantly larger $\hat{L}_\infty$ for females than males in this study was not consistent with results for the Kimberley stock. It is possible that these differences between studies could be attributed to localised environmental and/or anthropogenic effects such as fishing. A larger average body size for more southern Gascoyne stocks is consistent with theoretical expectations of latitudinal effects on body size (Atkinson 1994). Alternatively, since fishing typically captures larger, faster growing fish in a population, and the Kimberley stock has been fished intensively for two decades longer than the Gascoyne stock, the smaller $\hat{L}_\infty$ in the Kimberley could be an apparent change in growth rate resulting from greater historical fishing pressure (e.g, Moulton *et al* 1992). Other factors potentially affecting localised growth could also be habitat dependent, since the stock in the Gascoyne is distributed in slightly deeper depths, on average, than the stock in the Kimberley.

## 5.3.3 Recruitment

There have been no studies on the recruitment of this species. In Indonesia, however, genetic subdivision was apparent over relatively small spatial scales, suggesting that all life stages of this species may be relatively sedentary (Ovenden *et al.* 2004). From the study of stable isotope ratios within otoliths, Newman et al. (2000) suggested limited movement of post-settlement individuals between study areas within northern Australia and between northern Australia and Indonesia. Lloyd *et al.* (1996) found that goldband snapper stocks in the Kimberley and Northern Territory were genetically distinct, indicating that recruitment may be relatively localised, at least within their relatively large study areas.

### 5.3.4 Reproduction

#### 5.3.4.1 Introduction

The reproductive biology of goldband snapper has not been studied in the Gascoyne but was previously described for Kimberley fish by Newman et al. (2001). That study found that this species is functionally gonochoristic, determined the length and age at maturity of females and males, and defined their reproductive period (peak in March) and sex ratio (slightly male biased). A relatively late average age at maturity of 8 years for males and females indicated relatively slow rates of population turnover and low production potential for fishing this stock (Newman *et al.* 2001).

Reproductive biology of goldband snapper in the South China Sea was studied by Min *et al*. (1977). The study analysed relative gonad weights to find evidence of a prolonged spawning season and counted all developing oocytes within relatively large ovaries during the spawning season for preliminary estimates of fecundity. However, those counts would have been over-estimates of batch fecundity because they found evidence of multiple modes in frequency distributions of oocyte diameters, as did Newman *et al.* (2001) for Kimberley populations, indicating that this species displayed asynchronous oocyte development.

#### 5.3.4.2 Methods

Gonadosomatic index (GSI) values were calculated for females and males using,

$$GSI = 100 \times GW/BW$$

where BW = total body weight (g) and GW = gonad weight (g).

Since BW data were not available, BW was estimated from length (FL: mm) measurements according to the described BW: FL relationship by Newman and Dunk (2003) for the Kimberley stock. Mean GSIs (and their standard errors) were plotted for each month, pooled across years. The monthly percentage contributions of ovaries that were macroscopically staged as either ‘developed’ (stage 4) or ‘spawning’ (stage 5) were also used to determine spawning period. These stages were grouped together as the ‘ripe’ category for females and males. Data were pooled across years in order to maximise the resolution of this analysis, given that adequate numbers of specimens were not collected over consecutive months for any twelve-month period.

#### 5.3.4.3 Results

Trends exhibited by mean monthly GSIs for both sexes were similar, indicating a peak period of reproduction from March to May (Fig. 5.3.6.). The monthly proportions of ‘ripe’ females corroborated the seasonal pattern in mean GSI for females, with high proportions observed from January through to June and low proportions from July to December. The correlation between mean monthly GSIs and percentage contributions of ‘ripe’ fish, however, was not as strong for males, because although high proportions were sampled in February and March, relatively low proportions were sampled in April and May, increasing slightly to represent approximately half of those specimens collected in June and July (Fig. 5.3.6.). ‘Ripe’ ovaries were recorded over a slightly longer, but overlapping, period (January to August, November) than ‘ripe’ testes (February to July).

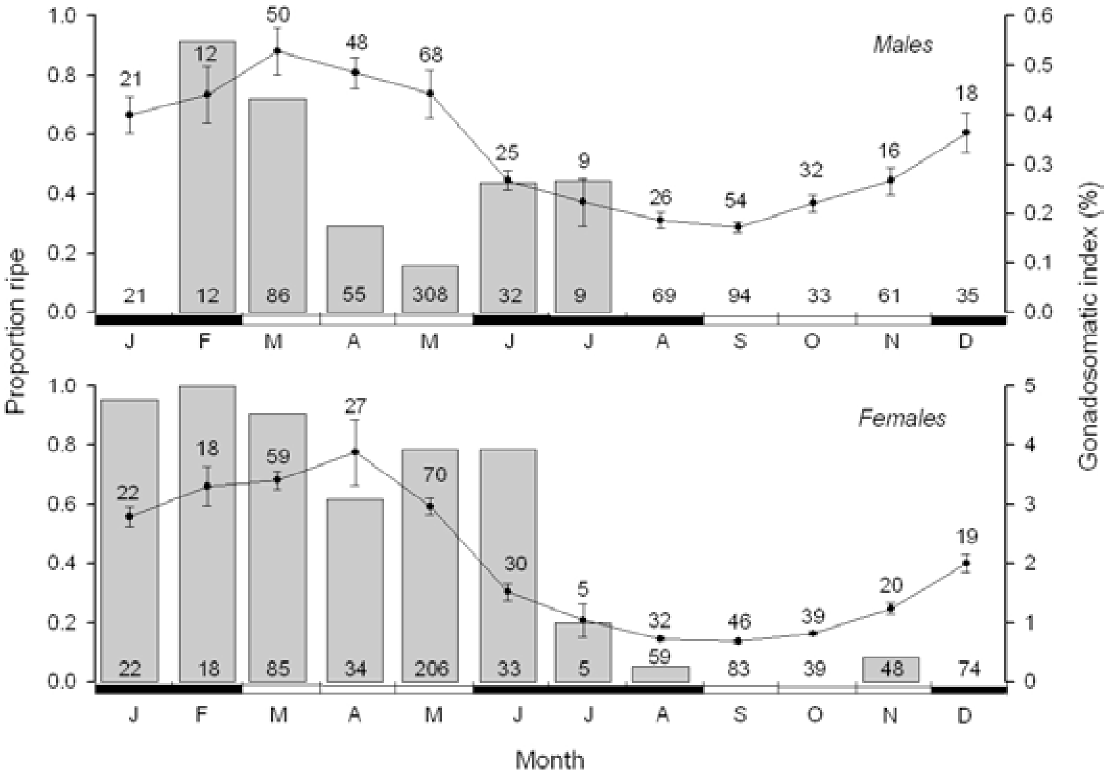



**Figure 5.3.6.** Mean monthly gonadosomatic indices (±1 SE, line, sample sizes above) and monthly proportions of goldband snapper with 'ripe' gonads (stage 4 and 5 gonads, bars, sample sizes below) collected 2004-2008. On the x-axis, black rectangles represent austral summer and winter and white rectangles spring and autumn.

The body weights of females in spawning mode were investigated as a proxy for relative fecundity. There was a significant linear relationship between female body weight (g) with ovary weight (Pearsons $r = 0.537$, $p < 0.001$).

#### 5.3.4.4 Discussion

The spawning period and sex ratio of goldband snapper in the Gascoyne are consistent with those found in the Kimberley (Newman *et al.* 2001). Although length and age at maturity were not investigated in this study, there may be differences in these characteristics between the two regions because significant differences in size at age were observed between areas (Section 5.3.2). For instance, a different average length at age for goldband snapper in the Gascoyne predicts that even if the average length at maturity in both areas is similar, the average age at maturity would likely be different. Length and age at maturity needs further investigation for Gascoyne populations.

### 5.3.5 Other factors influencing susceptibility to exploitation

There is currently no MLL in place for goldband snapper in Western Australia. Fish of less than 30 cm TL are rarely observed in commercial catches that account for most of the catch in the Gascoyne. Barotrauma-induced discard mortality could potentially become an issue if a MLL was introduced or as recreational fishing activities shift towards catch and release of this species given that goldband are mostly taken in waters 150-250 m depth. It has previously been reported that this species is likely to be sensitive to post-release mortality (Newman and Dunk

2003) although there is no evidence for the discarding of goldband snapper by the commercial sector.

Aggregations of goldband snapper that occur over hard bottom areas can also be easily identified using GPS and colour sounder equipment (Newman *et al.* 2001). The targeting of these aggregations can result in relatively high catch rates that can be maintained by a mobile fishing fleet. Such "hyperstable" (Hilborn and Walters 1992) catch rates can potentially mask localised depletions and are therefore an important consideration for future monitoring and management of the stock.

# 6.0 Fishery characteristics and stock assessments

## 6.1 Catch and effort information for key indicator species

### 6.1.1 Introduction

Seasonal fishing patterns in the Gascoyne Coast Bioregion have historically been similar between the sectors with peaks in commercial and recreational fishing occurring during winter (Sumner *et al*. 2002; Moran *et al.* 2005). Spatial patterns, however, have differed due to the sector-specific management controls used in different parts of the Bioregion and differences in the main areas of the respective fishing operations. Catch and effort (C&E) information for the three inshore demersal indicator species for the commercial, charter and recreational (boat-based) sectors are presented and trends described in the following sections.

Recreational and charter data are reported for "recreational" years (1 April to 31 March) and commercial data reported for "commercial" years (1 September to 31 August; see Section 4.4 for details).

### 6.1.2 Methods

#### 6.1.2.1 Commercial catch and effort

Commercial C&E data for the Gascoyne Coast Bioregion were obtained from the DoFWA Catch & Effort Statistics (CAES) for the period 1975/76 to 2007/08*. As the focus here was the three indicator species, the CAES data used were limited to categories of gear that target demersal scalefish species and included handline (HL), dropline (DL), longline (LL) and fish traps (FT) but not other gear types (e.g. trawl, haul nets, seine nets etc). Commercial C&E data were reported via compulsory monthly logbooks† that use a 60 x 60 nautical mile (nm) grid of reporting blocks (represent approximately 1$^{o}$ squares of longitude x latitude).

Prior to 1987 all commercial fishing that targeted demersal scalefish in the Gascoyne using the above gear types was categorised as 'wetline' (see Crowe *et al.* 1999 for definitions). Commercial fishing for pink snapper in oceanic waters outside Shark Bay and northern waters inside Shark Bay came under management for the first time in 1987 with the creation of the Shark Bay Limited Entry Fishery (became the Shark Bay Snapper Managed Fishery [SBSF] in 2001, 'Shark Bay Snapper') (Moran *et al.* 2005). Commercial trap fishing in the Pilbara (north of 21°56'S) came under management in 1992 ('Pilbara Trap') (Moran *et al.* 1993). In addition, some line fishing (HL) was also undertaken in Zones 1 & 2 by trawlers operating within the Shark Bay Prawn Fishery and in the inner gulfs, by Shark Bay Beach Seine and Mesh Net Fishery vessels ('Shark Bay Trawl/Beach Seine').

The accuracy of species identification for some categories within CAES has been uncertain in the past, in particular, spangled emperor and goldband snapper.

Spangled emperor was initially recorded with other lethrinid species in the "North West Snapper" category. The proportion of species that made up this category was monitored by the Department for commercial trap and line fishing catches from July 1986 to June 1988 and for the "Ningaloo" study area landed catches of North West Snapper comprised 53% spangled

* Commercial C&E data have been reported to the DoFWA since 1941. The Catch And Effort Statistics (CAES) system that was developed by the Australian Bureau of Statistics in 1967 remains the main reporting system for commercial fishing data in WA.

† Daily/trip logbooks were introduced for SBSF vessels in February 2008; 'wetline' vessels in the Gascoyne continued to use monthly returns for the periods included in this study.

emperor, 27% redthroat (sweetip) emperor and 20% other species (Moran *et al.* 1988). The North West Snapper category was refined in 1993 by dividing these catches into "Large" and "Small" North West Snapper. Catches of spangled emperor were then recorded by commercial fishers for entering into the database as Large North West Snapper. The "Spangled emperor" category for data entry was created in January 2000. However, since 1993 a small number of commercial operators have continued to report catches of spangled emperor within the "Large North West Snapper" and "North West Snapper" categories. Therefore, all reporting of commercial catches for spangled emperor are the combined total across the three species name categories. Relatively recent spatial maps of catches of the combined North West Snapper, Large North West Snapper and Spangled emperor categories are assumed to represent mainly spangled emperor.

The potential influence of pooling species identification categories is shown in Figure 6.1.1 as the percentage breakdown of those categories comprising the pooled Spangled emperor group since the "Spangled emperor" species category was implemented. This shows that the majority of the commercial catch has been recorded as this species in recent years, since this species category has been available in the database, except for a notably lower percentage recorded as spangled emperor (57.5%) recorded in 2003/04. This analysis complements the previous analysis by Moran *et al.* (1988) to indicate the potential influence of variability in species identification on subsequent analyses of catch and catch rates in this chapter.

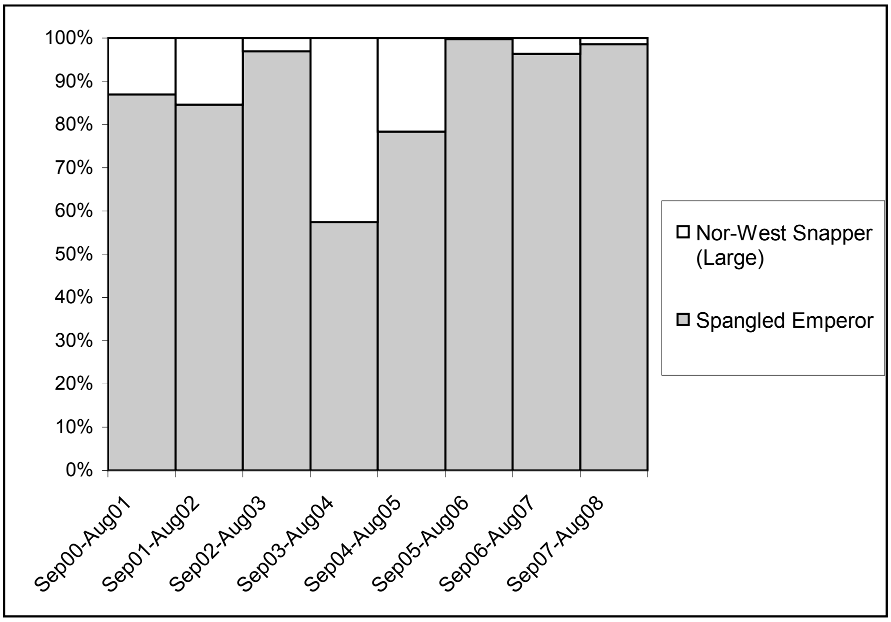



**Figure 6.1.1** Species identification categories grouped together as "Spangled emperor" as percentages of total annual commercial catches in the Gascoyne Coast Bioregion from 2000/01 to 2007/08. "Spangled emperor" species category (grey) comprises "spangled emperor", 351008; and "snapper nor-west (spangled emperor)", 351000)

Goldband snapper were initially recorded with other lutjanids in the category "Jobfish" (e.g., rosy jobfish, sharptooth snapper) until September 1995 when new database labels were created for each of these separate species. From inspection of commercial catch data from the Gascoyne bioregion, no further catches were recorded in the combined "Jobfish" category after 1998. Therefore, goldband snapper are presented here for combined catches of database categories "Jobfish", "Goldband snapper", "Rosy jobfish" (*P. filamentosus*) and "Sharptooth snapper" (*P. typus*). Catches of goldband snapper have been demonstrated to make up approximately 60-85%

of this Jobfish category by landed weight in more recent years and therefore trends represented for Jobfish catches are assumed to represent those for goldband catches (Fig. 6.1.2). The relatively small contribution of other species recorded in the pooled Goldband snapper group demonstrates that subsequent analyses of catches and catch rates primarily comprise those for the Goldband snapper species category. Accordingly, the analysis supports the assumption of a negligible influence of catches of Rosy snapper, Sharptooth jobfish, and other jobfish on catch and catch rate analyses presented for Goldband snapper in this chapter.

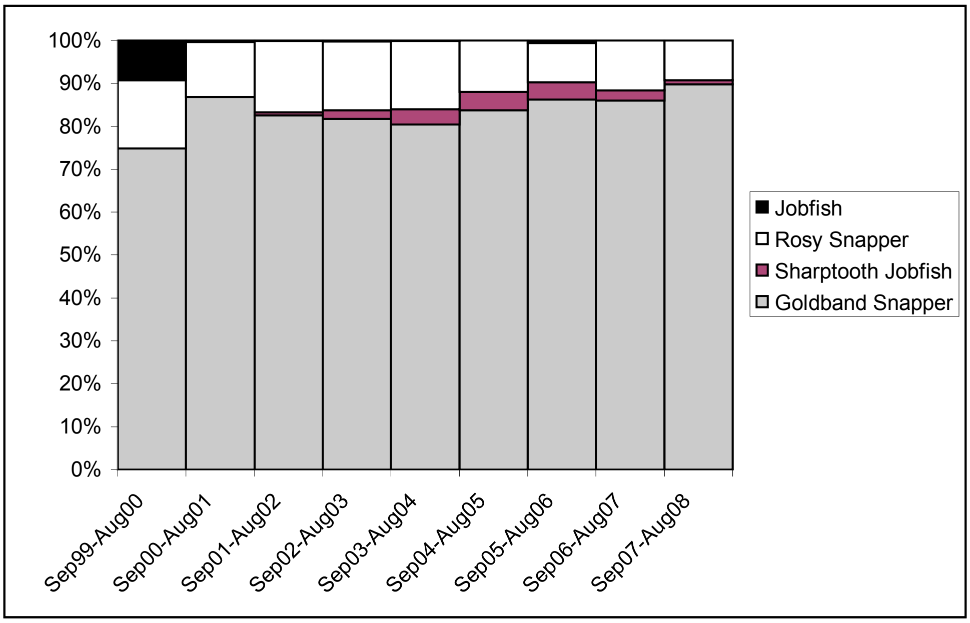



**Figure 6.1.2** Species identification categories grouped together as "Goldband snapper" as percentages of total annual commercial catches in the Gascoyne Coast Bioregion from 1999/00 to 2007/08.

CAES C&E data were summed across months for each 'year' of fishing (see Section 4.4) and apportioned for blocks straddling zone boundaries on the basis of map area occupied by each of those blocks in each of the respective adjacent zones. Spatial apportionments of C&E therefore assumed no influence of depth or other factors (e.g. habitat) on the spatial or temporal distribution of catches within CAES blocks or months. This assumption was applied to the apportionment of C&E between all management zones except for Zones 4 and 5. The apportionment of commercial catches from each CAES block (60 x 60 nm) to the relatively narrow (3-10 nm wide) Zones 4 and 5 on the basis of map area alone would have likely underestimated the influences of changing depth and habitat on available scalefish biomass (in particular, of spangled emperor). Therefore, the coarser spatial units of commercial C&E data were reported in aggregate for Zone 4 with Zone 2 and for Zone 5 with Zone 6.

In the case of commercial catch data, once the catches for straddling blocks were spatially apportioned among zones, block catches for each zone were summed across fisheries, vessels, methods and months to derive catch estimates for each zone. In the case of commercial effort data, however, some further manipulation was required to account for the occasional duplication of effort records for any vessel fishing in a block and a month that was simultaneously operating under different fishery licences and/or using different gears. Therefore, once effort data for straddling blocks were spatially apportioned among zones ("estimated blockdays"), the proportion of fishing days expended by each vessel was calculated for every block fished and method used, within each fishery and month, i.e.

For each vessel, fishery and month:

$$Proportion.Blockdays_{Block,Method} = \frac{estimated.blockdays_{Vessel,Fishery,Month,Block,Method}}{estimated.blockdays_{Vessel,Fishery,Month}}$$

$$where:$$
$$\sum_{Vessel,Fishery,Month} Proportion.Blockdays_{Block,Method} = 1$$

Unadjusted effort days for each method that were recorded for each block ("block days") were then summed for groupings of vessel, fishery and month for comparison with the number of total days fished by each vessel in each fishery and month ("total days"), which was recorded by fishers as a separate entry on the logbook returns. If the summed block days exceeded the total days, this indicated the aforementioned duplication of effort data at the block level, and so the more conservative total day values were used, i.e.

$$Days_{Vessel,Fishery,Month} = \begin{cases} \sum\limits_{Vessel,Fishery,Month} block.days > total.days_{Vessel,Fishery,Month} = total.days_{Vessel,Fishery,Month} \\ \sum\limits_{Vessel,Fishery,Month} block.days \le total.days_{Vessel,Fishery,Month} = \sum\limits_{Vessel,Fishery,Month} block.days \end{cases}$$

Adjusted effort days ("adjusted days") were then calculated by multiplying the proportions by the effort term aggregated at the level of vessel, fishery and month accordingly:

$$adjusted.days_{Vessel,Fishery,Month,Block,Method} = Proportion.Blockdays_{Block,Method} \times Days_{Vessel,Fishery,Month}$$

and effort days for each assessment zone and fishery were calculated as the sum of adjusted days for blocks situated within each assessment zone for each fishery, across all months, vessels and demersal scalefish fishing methods.

#### 6.1.2.2 Recreational catch and effort

Catch and effort data were collected from recreational boat-based anglers fishing in the Gascoyne Bioregion during two 12-month creel surveys. These research surveys were conducted almost a decade apart, between 1 April 1998 to 31 March 1999 and 1 April 2007 to 31 March 2008. The analysis of these data produced estimates of the annual fishing effort and catch for ocean line fishing by these fishers.

Detailed results from the original analysis of the data collected in the 1998/99 survey have been presented by Sumner *et al*. (2002). In 2009, a review of the methods used in Western Australia's boat-ramp based creel surveys was undertaken (Steffe, 2009). A workshop to examine the results of this review was held in October 2009 to determine how its recommendations might best be implemented (Fletcher *et al.* 2012). The analysis used to produce the results presented in this report is based on these recommendations.

#### 6.1.2.2.1 Design

For the 1998/99 and 2007/08 surveys, 11 public boat ramps represented the key access points for the Gascoyne Bioregion. Boats launched from the shore and from other access points were not included in these results. Because of the distances between the various boat ramps, it was not possible for the research team to visit all boat ramps on a single survey day. Extending the visit over multiple days would potentially introduce double counting, as the same boat could be encountered at different boat ramps on different days. Accordingly, it was decided that the 11 boat ramps should be combined into groups such that each of the boat ramps within the group could be visited on the same survey day, and to minimise travel time and cost. Thus, the 11 boat ramps in the Gascoyne Bioregion were divided into four geographic groups, where the Coral Bay group comprised a single boat ramp (Figure 6.1.3). The boat ramps in each group were arranged in the form of a “bus route”, i.e. a specified sequence of boat ramps, such that, on each survey day, the research team started it’s survey at a randomly-selected boat ramp within the route then, with a randomly-selected direction of travel, progressively visited each of the ramps in the sequence defined by the “bus route”.

With the above design, the recreational survey for the Gascoyne Bioregion was broken down into four separate surveys, i.e. one survey for each bus route. Data collected for each bus route were analysed separately. The primary sampling unit for each of these four independent bus route surveys was the bus route survey day. Catch and effort data for these primary sampling units were combined over different survey days within each temporal stratum (season) to produce seasonal estimates of catch and effort for boat-based, ocean-line fishing for recreational fishing boats operating from the public boat ramps within the bus route. It was only at the conclusion of the analyses for the individual bus routes that estimates of the total seasonal and annual catches and fishing effort for the Bioregion were calculated by combining the data from the individual bus routes. The bus routes thus act as the top-most strata in the analysis of the data, and have been treated as such in the methods that are described below.

It should be noted that, depending on the geographic separation of the boat ramps in the different bus routes and the ranges over which fishers from the different bus routes travel, the waters fished by fishers operating from the boat ramps of one bus route may overlap the waters fished by those operating from another bus route. This is taken into account through the methods described below. The four bus routes to which the public boat ramps of the Gascoyne Bioregion were assigned for the 1998/99 and 2007/08 surveys may be associated with the various management assessment zones in this Bioregion (Figure 1.1, Table 6.1.1). The survey’s sampling design, however did not allow catch and fishing effort to be estimated for the Ningaloo Marine Park, i.e. Management assessment zone 4 and 5.

**Table 6.1.1** The four bus routes used in the 1998/99 and 2007/08 recreational boat-based fishing surveys of the Gascoyne Bioregion, together with the number of boat ramps within each bus route and the assessment zones (Section 1, Figure 1.1) with which fishing within that route is associated.

| Bus route | Number of boat ramps | Management assessment zones |
|---|---|---|
| Exmouth | 3 | 5, 6, 7 |
| Coral Bay | 1 | 2, 4, 5, 6 |
| Carnarvon | 4 | 2 |
| Shark Bay | 3 | 1 |

In determining the appropriate start and finish time prior to the commencement of the 1998/99 survey, discussions with regional Fisheries and Marine Officer, local community members and a pilot survey assisted in deciding that few vessels were retrieved at the boat ramps before 11:00 a.m., that most activity occurred in the later half of the day, and that most recreational boats had returned to the boat ramps by 6:00 p.m. The 1998/99 survey of the boat ramps was therefore restricted to the seven hour period from 11:00 a.m. to 6:00 p.m. The 2007/08 survey employed the same daily survey period to ensure direct comparability of the results obtained from the two surveys.

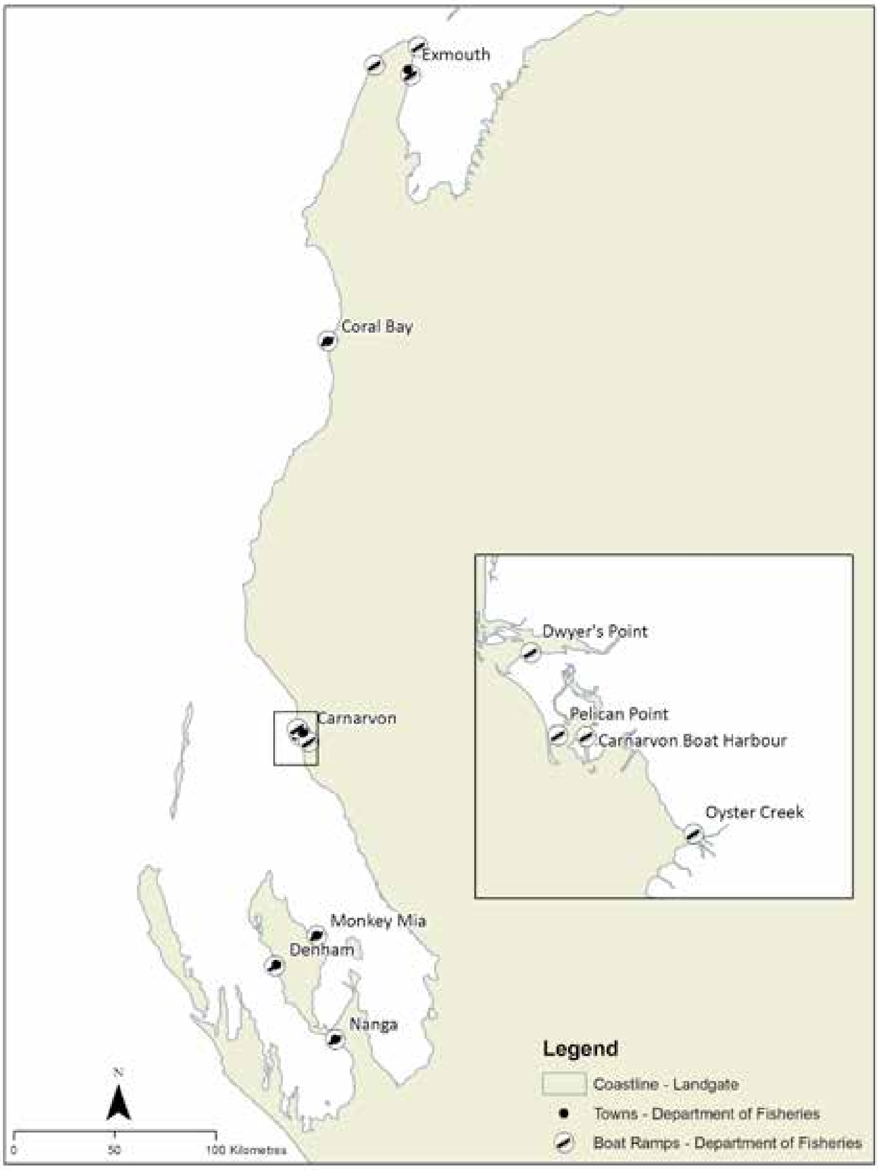



**Figure 6.1.3** Boat ramp locations for each of the four geographic bus routes

As noted above, the bus route method required that the research team, i.e. the interviewers, visited all of the boat ramps within the bus route on each randomly-selected day. Whilst at each ramp, the count of boat trailers was recorded and interviews of recreational fishers were undertaken (Robson & Jones 1989, Jones et al. 1990). When interviewers were at each boat ramp, they attempted to interview as many recreational boat crews as possible. When several boats returned to the ramp at the same time, the survey interviewers randomly chose which of the boat crews to interview. Interviewers were trained in the use of the interview data sheets, which were slightly, but not substantially modified between the 1998/99 and 2007/08 surveys (Appendix 2, IV). In 2007/08, questions were introduced asking whether the party on board each boat had engaged in fishing (yes or no) and, if so, how many of the individuals in the party had fished. In the same survey, the following questions were removed from the interview sheet as they were no longer relevant to the study: number of females on the boat, the age group of the interviewee, whether the interviewee was a member of an angling club, and the number of times that the party on board the boat had previously been interviewed.

The combination of bus routes and seasonal divisions resulted in an experimental design with 16 strata (4 bus routes x 4 seasons). The number of sample days, interviews and fishing interviews in parenthesis for each bus route was assumed to be representative of the population of fishing boats (Table 6.1.2).

**Table 6.1.2** The number of sample days, interviews and fishing interviews in parenthesis for each bus route.

| Bus Route | Survey year | 1998/99 | 2007/08 |
|---|---|---|---|
| Exmouth | Sample days | 71 | 98 |
| | Interviews | 651 (576) | 1434 (1312) |
| Coral Bay | Sample days | 61 | 106 |
| | Interviews | 512 (349) | 827 (743) |
| Carnarvon | Sample days | 64 | 77 |
| | Interviews | 150 (126) | 163 (131) |
| Shark Bay | Sample days | 86 | 96 |
| | Interviews | 481 (462) | 423 (375) |

The days on which each bus route was surveyed were chosen randomly within each month, thereby ensuring that surveyed days were spread throughout each season. For each randomly-selected survey day for each bus route, randomised schedules of boat ramp visits covering all ramps in the route were then developed. The schedules specified the order in which the boat ramps were to be visited and the amount of time that was to be spent at each ramp. The survey interviewers spent more time at busy boat ramps to maximise the amount of recreational data collected. Pilot surveys were undertaken to determine the amount of time to be spent at each boat ramp, prior to the commencement of each survey. The resulting proportion of time spent at each boat ramp for each of the 1998/99 and 2007/08 surveys is shown in Table 6.1.3.

**Table 6.1.3** Proportion of time spent at each boat ramp per bus route in the 1998/99 and 2007/08 surveys.

| Bus Route | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Exmouth<br>1998/99<br>2007/08 | Exmouth Marina<br>20%<br>50% | Bundegi<br>40%<br>10% | Tantabiddi<br>40%<br>40% | |
| Coral Bay<br>1998/99<br>2007/08 | Boat Ramp<br>100%<br>100% | | | |
| Carnarvon<br>1998/99<br>2007/08 | Oyster Creek<br>10%<br>10% | Carnarvon Boat Harbour<br>45%<br>45% | Dwyer's Point<br>5%<br>5% | Pelican Point<br>40%<br>40% |
| Shark Bay<br>1998/99<br>2007/08 | Nanga<br>35%<br>45% (May-July)<br>25% (Sept)<br>30% (all other times) | Denham<br>40%<br>30% (May- July)<br>30% (Sept)<br>35% (all other times) | Monkey Mia<br>25%<br>25% (May – July)<br>45% (Sept)<br>35% (all other times) | |

For example based on the table 6.1.3, a survey interviewer's schedule of time allocated to each boat ramp in the Exmouth bus route in 2007/08 could have been:

- Exmouth Marina - 11:00am to 2:15pm
- Bundegi - 2:27pm to 3:06pm
- Tantabiddi - 3:24pm to 6:00pm

Recreational fishers at boat ramps were required to identify the 5 x 5 nautical mile blocks in which they had fished.

Estimates of catch and effort were produced for each bus route and also for zone 1; combined zones 2 and 4 and combined zones 5, 6 and 7. As one of the bus routes straddled the boundaries between management zones 2 and 6, when estimating the catch and effort for the management zones, the catch and effort recorded for each 5 x 5 nautical mile block were divided among the zones in proportion to the areas of those zones within the block. There are no estimates for zone 3 as no recreational interviews were recorded for catches made in this area.

#### 6.1.2.2.2 Analysis

The sampling frame for each bus route was the set of all possible days on which the bus route could be surveyed, i.e. all possible survey days, during each temporal stratum. From this sampling frame, a random sample of survey days on which the bus route was to be surveyed was selected. All of the boat ramps in the bus route were visited during the daily survey period. The boat ramp to be visited at the start of the daily survey period for each sampled survey day, and the subsequent direction of travel around the boat ramps in the bus route, were randomly chosen. The primary sampling unit (PSU) was the sampling day. The survey design employed the different bus routes as the primary level of stratification and, by using season as a secondary level of stratification, provided coverage through the entire survey year.

An estimate of total fishing effort for the PSU, was derived from the data collected at each of the boat ramps. The daily data for the sampled PSUs within each stratum were then expanded to produce an estimate of the total fishing effort over all possible survey days within the stratum.

Subsequently, the catch rate over all possible survey days within each stratum was calculated and used, in combination with the estimate of fishing effort, to calculate an estimate of the total catch over all possible survey days within each stratum. Finally, the data for the different strata were combined to obtain an estimate of the total catch and total effort.

As noted earlier, the Gascoyne bioregion surveys were restricted to a specified period within each day, i.e. from 11:00 a.m. to 6:00 p.m. from 1 April 1998 to 31 March 1999 (Sumner et al., 2002) and 1 April 2007 to 31 March 2008. The interviewer moved around the bus route visiting each boat ramp according to the predefined schedule, such that the time spent at each ramp was approximately proportional to the relative activity that was expected to be recorded at the various ramps. The schedule allowed for the travelling time between boat ramps. The time that the interviewer spent at each boat ramp $r$ ($1 \le r \le R$) on sampling day $d$ ($1 \le d \le D_m$) within stratum $m$ ($1 \le m \le M$) is referred to as the wait time $w_{rdm}$.

Pollock et al. (1994) advised that the interviewer needed to adhere strictly to the schedule of visits, i.e. the time of arrival at the boat ramp and the specified wait time at that ramp. In practice, a small amount of implementation error occurred in the boat ramp surveys undertaken. Accordingly any inconsistency between the actual scheduled times were determined from the start and end times at the boat ramp that were recorded by the interviewer rather than the scheduled times.

At the beginning and end of the visit to each boat ramp, i.e. at times $t_{rdm}$ and $t_{rdm} + w_{rdm}$, respectively, the interviewer recorded the number of boat trailers that were parked at the boat ramp. The time at which each boat $b$ was launched $l_{rbdm}$ or retrieved $r_{rbdm}$ during the wait time on this sampling day was recorded. Launch and retrieval times falling outside the wait time were considered to be missing (unknown) values. Note that each boat trailer parked at a boat ramp was assumed to be associated with a boat that had been launched from that ramp. The boats associated with these trailers were included in the total number of boats, i.e. the boats considered include all boats launched or retrieved during the wait time as well as those boats which remained on the water throughout the entire wait time.

In addition to recording the launch and retrieval times of each boat, the interviewer attempted to interview a member of the party that was aboard each boat that was retrieved at the boat ramp. During the interviews, details of the launch time of the retrieved boat and the duration of fishing were ascertained and recorded by the interviewer, together with details of catches of the different species and, where practical, lengths of individuals of retained species.

#### 6.1.2.2.3 Calculation of total fishing time for the whole bus route for each surveyed day

In the first section of this analysis, all boats were included, whether involved in fishing or in non-fishing activities, and whether or not an interview was conducted. Subsequently, the question of whether or not the boat was fishing was addressed.

Let $X_{rbdm}$ be the time that boat $b$ ($1 \le b \le B_{rdm}$) is on the water (or the trailer associated with boat $b$ is at the ramp) while the interviewer is at ramp $r$ on sampling day $d$ within stratum $m$. The value of $X_{rbdm}$ was calculated as shown in Table 6.1.4. The estimate of the total boat time (hours) $e_{dm}$ during the daily survey period $T$ over all boat ramps $r$ $(1 \le r \le R)$ on day $d$ $(1 \le d \le D_m)$ in stratum $m$ $(1 \le m \le M)$ (Jones and Robson, 1991) is

$$e_{dm} = T \sum_{r=1}^{R} \frac{1}{w_{rdm}} \sum_{b=1}^{B_{rdm}} X_{rbdm}$$

**Table 6.1.4.** Approaches used to calculate the value of $X_{rbdm}$, the time that boat $b$ $(1 \le b \le B_{rdm})$ was on the water (or the trailer associated with boat $b$ is at the ramp) while the interviewer was at ramp $r$ on sampling day $d$ within stratum $m$. Note that an estimate of the launch time $\hat{l}_{rbdm}$ for a boat that was launched prior to the start of the visit to the boat ramp was available only if the party on board the boat was interviewed.

| | | Retrieval | | |
|---|---|---|---|---|
| | | **Before visit to boat ramp** | **During wait time** | **After visit to boat ramp** |
| Launch | Before visit to boat ramp | No overlap with visit | $X_{rbdm} = r_{rbdm} - t_{rdm}$ | $X_{rbdm} = w_{rdm}$ |
| | During wait time | NA | $X_{rbdm} = r_{rbdm} - \hat{l}_{rbdm}$ | $X_{rbdm} = t_{rdm} + w_{rdm} - l_{rbdm}$ |
| | After visit to boat ramp | NA | NA | No overlap with visit |

This calculation assumed that the times at which all boats were launched or retrieved during the wait time were accurately recorded, that the number of trailers in the ramp at the start of the wait time were accurately recorded, and that the wait time was a random sample of duration $w_{rdm}$ from the time period $T$, which, based on the preliminary survey undertaken prior to the surveys, was assumed to represent a good approximation to the total time within the sampling day during which fishing was likely to have occurred. However, it is noted that boat ramps where the proportion of time spent over the sampled day was 10% or less (Table 6.1.3) may not have produced data that were representative of activity over the total time within the sampling day. No record was kept by the interviewer of the identities of boats that were launched during the visit to the ramp. It was thus not possible to determine whether a retrieved boat was launched prior to or after the start of the wait time. Accordingly, it was assumed that all boats that were retrieved during the visit were launched prior to the start of the wait time, and that all boats launched from the boat ramp during the visit were retrieved after the conclusion of the visit to the boat ramp. Thus, the number of boats that were present at the ramp for the entire duration of the visit was calculated as the difference between the number of boat trailers present at the start of the visit and the number of retrievals (or zero, if this difference was negative).

To facilitate the calculation of the variance of total boat time for the stratum for those cases where there was a limited number of boats at a boat ramp during the bus route survey, the above equation for $e_{dm}$ was re-written in terms of a transformed variable, $X'_{rbdm}$. For boat (or trailer) $b$ at boat ramp $r$ on survey day $d$ within stratum $m$, the boat time for each unit of survey time within the interviewer's visit was calculated as

$$X'_{rbdm} = \frac{X_{rbdm}}{w_{rdm}}$$

The average boat time for each unit of survey time for all boats at boat ramp *r* on survey day *d* within stratum *m* was then calculated as

$$\overline{X}'_{rdm} = \frac{1}{B_{rdm}} \sum_{b=1}^{B_{rdm}} X'_{rbdm}$$

where

$$Var\left(\overline{X}'_{rdm}\right) = \frac{1}{B_{rdm}\left(B_{rdm}-1\right)} \sum_{b=1}^{B_{rdm}} \left(X'_{rbdm} - \overline{X}'_{rdm}\right)^2$$

This boat ramp-based estimate of variance is undefined if $B_{rdm} < 2$. If the number of boats at boat ramp *r* on survey day *d* within stratum *m* was insufficient to allow calculation of the variance using the above equation, a stratum-based estimate of the variance for this ramp, day and stratum was obtained by calculating the variance over all boats, ramps and survey days within the stratum. Thus, in this case,

$$Var\left(\overline{X}'_{rdm}\right) = \frac{1}{\left(\sum_{d=1}^{d_m}\sum_{r=1}^{R} B_{rdm}\right)\left(\sum_{d=1}^{d_m}\sum_{r=1}^{R} B_{rdm} - 1\right)} \sum_{d=1}^{d_m}\sum_{r=1}^{R}\sum_{b=1}^{B_{rdm}} \left( X'_{rbdm} - \frac{1}{\left(\sum_{d=1}^{d_m}\sum_{r=1}^{R} B_{rdm}\right)} \sum_{d=1}^{d_m}\sum_{r=1}^{R}\sum_{b=1}^{B_{rdm}} X'_{rbdm} \right)^2$$

where $d_m$ was the number of sampled survey days within the stratum on which the bus route survey was undertaken, and where it was assumed that the values of $X'_{rbdm}$ are random variates sampled from the stratum. As previous studies of recreational boat survey data within Western Australia had applied a stratum-wide estimate of variance rather than a ramp-based estimate, the analyses undertaken in this study considered the cases where (a) the stratum-based estimates of variance were used only for those boat ramps and sampled survey days on which the number of boats was less than 2, and (b) the stratum-based estimates of variance were used for all boat ramps and sampled survey days.

The total boat time of the boats at ramp *r* on sampling day *d* within stratum *m* during the wait time at this site was calculated as $TB_{rdm}\overline{X}'_{rdm}$, and the variance of this variable was estimated as $\left(TB_{rdm}\right)^2 Var\left(\overline{X}'_{rdm}\right)$.

The total boat time over all boat ramps in the bus route, i.e. the PSU, on day *d* in stratum *m* was

$$e_{dm} = T\sum_{r=1}^{R} B_{rdm}\overline{X}'_{rdm}$$

with variance

$$Var\left(e_{dm}\right) = T^2 \sum_{r=1}^{R} B_{rdm}^2 Var\left(\overline{X}'_{rdm}\right)$$

where it was assumed that the estimates of $\overline{X}'_{rdm}$ for the different boat ramps were independent.

The equations presented above describe how estimates of total boat time were calculated for the various strata. For fishing time, it was necessary to adjust the equations to allow for boats that were not occupied in fishing activity, noting that determination of whether or not a boat was engaged in fishing was based on the results of the interviews that were conducted.

The calculation of fishing effort used the proportion of all retrieved boats over all boat ramps for the sampled survey day of boats that had been involved in fishing.

The Coral Bay bus route straddles the boundaries between assessment zones 2 to 6. Therefore, when calculating the effort for these management zones, it was necessary to assign the effort for those blocks that were entirely within a given management zone directly to that zone. However, when the boundary of the management zone passed through the 5 x 5 nautical mile blocks into which effort data had been recorded, it was necessary to apportion effort to each management zone on the basis of the proportion of the area within the block that fell within that management zone. Thus, for those recreational interviews reporting that fishing had occurred within 5 x 5 nautical mile blocks that straddled the boundary, the effort was apportioned into each of the respective adjacent management zones using the area of the block i.e. 40% zone 6 and 60% zone 2. This was facilitated by drawing a uniformly-distributed random number and comparing this with the value 0.4 to determine whether the data from that particular interview was to be assigned to zone 6 or zone 2. This assumed that all recreational interviews within the bus route had reported the 5 x 5 nautical mile block in which fishing had occurred. Note: only a small number of interviews in the earlier 1998/99 survey had missing block locations. The analysis was repeated for a number of trials (10,000), to produce an estimate of the uncertainty of the resulting catch and effort estimates. Note: the calculation could have been undertaken using the expected proportion of fishing in the block that lay within each zone.

For sampled survey day *d* within stratum *m*, the proportion of boats that fished (or fished for the targeted species and/or within a specified management zone), $p_{dm}$, was estimated as the ratio of the total over all boat ramps of the number of boats for which interviews reported (targeted) fishing for the day to the total over all boat ramps of the number of boats for which successful interviews were conducted.

The proportion $p_{dm}$ of boats that were fishing on day *d* in stratum *m* was estimated as

$$p_{dm} = \frac{n_{dm}^{Fishing}}{n_{dm}}$$

The variance of the proportion $p_{dm}$ was calculated as

$$Var(p_{dm}) = \frac{p_{dm}(1 - p_{dm})}{n_{dm}}$$

where $n_{dm}$ is the total number of interviews over all boat ramps for sampling day *d* within stratum *m*. If no boats were successfully interviewed on day *d* within stratum *m*, it was assumed that $p_{dm} = p_m$, where $p_m$ is calculated as the proportion of boats fishing over all ramps and days within the stratum (see next section). In this case, $Var(p_{dm})$ was assumed to be equal to $Var(p_m)$.

The total fishing time (hours of boat time) within the daily time period surveyed for day *d* within stratum *m* over all ramps included in the bus route, $e_{dm}^{f}$, was then estimated as

$$e_{dm}^{f} = p_{dm} e_{dm}$$

where the variance of $e_{dm}^{f}$ is calculated using the formula for the variance of a product presented by Goodman (1960, Eq. 5), i.e.

$$Var\left(e_{dm}^{f}\right) = \left(p_{dm} e_{dm}\right)^2 \left[\frac{Var\left(p_{dm}\right)}{p_{dm}^2} + \frac{Var\left(e_{dm}\right)}{e_{dm}^2} - \frac{Var\left(p_{dm}\right) Var\left(e_{dm}\right)}{\left(p_{dm} e_{dm}\right)^2}\right]$$

which has been employed in similar boat ramp studies of recreational fishing (e.g. Steffe *et al*. 2008).

#### 6.1.2.2.4 Calculating the fishing time over all possible sampling days within each stratum

The methods described above produced estimates over all boat ramps in the bus route for each sampled survey day *d* within each stratum *m*, i.e. for each sampled PSU, of the total fishing time within the daily survey period. The daily samples then needed to be combined to produce estimates for each stratum.

The total fishing time within the daily survey period for stratum *m* over all possible sampled survey days for the bus route was calculated as

$$\begin{aligned} \hat{E}_m &= \frac{D_m}{d_m} \sum_{d=1}^{d_m} e_{dm}^{f} \\ &= \frac{D_m}{d_m} \sum_{d=1}^{d_m} p_{dm} e_{dm} \end{aligned}$$

where the proportions of boats fishing were calculated over all boat ramps for the sampled survey day within the stratum.

The variance associated with $\hat{E}_m$ was estimated using

$$Var\left(\hat{E}_m\right) = \left(\frac{D_m}{d_m}\right)^2 Var\left(\sum_{d=1}^{d_m} p_{dm} e_{dm}\right) = \left(\frac{D_m}{d_m}\right)^2 Var\left(d_m \left[\frac{1}{d_m} \sum_{d=1}^{d_m} p_{dm} e_{dm}\right]\right),$$

where $Var\left(\sum_{d=1}^{d_m} p_{dm} e_{dm}\right)$ comprises a combination of both the variability among days and the imprecision of each product $p_{dm} e_{dm}$ .The variability among days may be estimated as the variance of the mean of $p_{dm} e_{dm}$, where it was assumed that each observation $p_{dm} e_{dm}$ had no error. The additional variability of the sum, $\sum_{d=1}^{d_m} p_{dm} e_{dm}$, that is associated with the error in the individual estimates of $p_{dm} e_{dm}$ was then considered to be the sum of the variances of those individual estimates, i.e. the sum of the values of $Var\left(p_{dm} e_{dm}\right)$.

Thus, correcting for the finite population over which the mean was estimated, the first term in the expression below represented the variability among the daily estimates, while the second term represented the variability associated with the imprecision of the products.

$$Var\left(\sum_{d=1}^{d_m} p_{dm}e_{dm}\right) = d_m^2\left[\frac{1}{d_m(d_m-1)}\left[\sum_{d=1}^{d_m}\left(p_{dm}e_{dm} - \frac{1}{d_m}\sum_{d=1}^{d_m} p_{dm}e_{dm}\right)^2\right]\left[\frac{D_m - d_m}{D_m}\right] + \left(\frac{1}{d_m D_m}\right)\sum_{d=1}^{d_m}\left[Var\left(p_{dm}e_{dm}\right)\right]\right]$$

where it was assumed that the products $p_{dm}e_{dm}$ were independent.

The standard error was calculated by the usual method

$SE(\hat{E}_m) = \sqrt{Var(\hat{E}_m)}$

#### 6.1.2.2.5 Calculating the average catch rate over all possible sampling days within each stratum

The catch rate for each stratum m was estimated as the ratio of the means for catch and effort (Crone & Malvestuto 1991), i.e.

$$\hat{R}_m = \frac{\bar{c}_m}{\bar{L}_m} = \frac{\sum_{b=1}^{n_m} c_{bm}/n_m}{\sum_{b=1}^{n_m} L_{bm}/n_m}$$

where $n_m$ is the number of interviewed boats in stratum *m*, and $c_{bm}$ is the catch and $L_{bm}$ is the length of trip, i.e. fishing effort, in hours on the water (i.e. the difference between launch and retrieval times), reported for interviewed boat *b*. Such an estimate of catch rate, calculated as the ratio of mean catch to mean effort, represents a measure of the weighted average of the catch rate for individual sampling units, where the fishing effort of each sampling unit is used as a weighting factor. The ratio of means is the appropriate estimator when the probability of interviewing a fisher is independent of fishing trip duration (*e.g.* when used for data from completed trips collected in an access-point survey such as boat-ramp based surveys) (Pollock *et al.,* 1994).

The variances for $\bar{c}_m$ and $\bar{L}_m$ were calculated by the usual method for the calculation of the variance of a mean of values within a sample (without the finite population correction factor).

The variance for $\hat{R}_m$ was then estimated using the formula described in Kendall & Stuart (1969)

$$Var(\hat{R}_m) \approx \hat{R}_m^2\left(\frac{Var(\bar{c}_m)}{\bar{c}_m^2} + \frac{Var(\bar{L}_m)}{\bar{L}_m^2} - \frac{2Cov(\bar{c}_m, \bar{L}_m)}{\bar{c}_m\bar{L}_m}\right)$$

The covariance term in this equation was assumed to be zero.

#### 6.1.2.2.6 Total catch for the stratum within the daily period surveyed

To estimate the total catch, the estimated total fishing effort (boat-hours) must be multiplied by the average daily catch rate. Thus the total catch $\hat{C}_m$ for stratum *m* was calculated as

$$\hat{C}_m = \hat{E}_m \hat{R}_m$$

and, using the formula presented by Goodman (1960, eq. 5), its variance as

$$Var(\hat{C}_m) \approx \hat{C}_m^2 \left( \frac{Var(\hat{E}_m)}{\hat{E}_m^2} + \frac{Var(\hat{R}_m)}{\hat{R}_m^2} - \frac{Var(\hat{E}_m)Var(\hat{R}_m)}{\hat{E}_m^2 \hat{R}_m^2} \right)$$

### 6.1.2.2.7 Combining the data over strata to produce estimates for the total fishery

The total catch for each bus route was estimated by summing the catch over all strata as follows

$$\hat{C} = \sum_{m=1}^{M} \hat{C}_m$$

The variance and standard error of $\hat{C}$ were estimated respectively as

$$Var(\hat{C}) = \sum_{m=1}^{M} Var(\hat{C}_m)$$

where the catches within the different strata are independent. The standard error of the total catch was

$$SE(\hat{C}) = \sqrt{Var(\hat{C})}.$$

A similar approach to that used when combining the catch data for each season to produce an estimate of the total annual catch for each bus route, i.e. the method described above, was employed to combine the seasonal and annual data for the various bus routes to produce catch estimates for the Gascoyne Bioregion.

### 6.1.2.2.8 Extrapolation of the catch from the daily sampling period to the full day

The analysis of the data collected in each bus route survey using the methods described above provided estimates of the total catch and effort within the daily survey period $T$ for the boat ramps covered by the bus route during the total period covered by the survey.

Extrapolation beyond the daily sampling period introduces further imprecision, however, and relies upon the assumptions under which the extrapolated estimates are calculated. The reliability and precision of the extrapolated values depend on the distribution of fishing activity within each day and the proportion of the total fishing activity that lies within the daily survey period. The extrapolation was constrained to the period for which data were collected in the daily survey period and thus does not necessarily provide "coverage" of the full period over which fishing activity occurs.

A correction factor $f$ was calculated using the data on launch times reported by the boat parties that were interviewed when their boats were retrieved at the boat ramps (Malseed and Sumner, 2001). The times at which boat $b$ was launched and retrieved at boat ramp $r$ on sampling day $d$ in stratum $m$ were denoted previously by $l_{rbdm}$ and $r_{rbdm}$, respectively, and the starting time of the wait time at the ramp was denoted by $t_{rdm}$. The factor by which the fishing effort (or catch) within the daily survey period was multiplied to include the additional boat time expended by fishers (who subsequently retrieved boats within the wait period) before the start of the daily survey period was estimated as

$$f_m = \frac{\sum_d \sum_r \sum_b (r_{rbdm} - l_{rbdm})}{\sum_d \sum_r \sum_b \min(r_{rbdm} - l_{rbdm}, r_{rbdm} - t_{rdm})}$$

No variance estimate was calculated for this factor, and therefore the variance of the extrapolated effort is likely to be slightly underestimated.

#### 6.1.2.2.9 Weight estimation of catches

The total lengths (cm) of fish in retained catches were not collected from all recreational interviews. The lengths of individuals of species with an adequate sample size of recorded fish lengths, however, were converted into estimates of fish weights using the following formulae:

Pink snapper (Zone 1)
Weight (g) = $1.48 \times 10^{-4} (0.8460 \times TL \text{ (mm)} + 0.3)^{2.6703}$

Pink snapper (Zone 2 to 7):
Weight (g) = $0.0467727 (0.8460 \times TL \text{ (cm)} +0.3)^{2.781}$

Spangled emperor (Zones 2 to 7):
Weight (g) = $6.002 \times 10^{-5} (TL \text{ (mm)} - 3.256)/1.11)^{2.810}$

Goldband snapper (All zones):
Weight (g) = $2.483 \times 10^{-5} ((0.89 \times TL \text{ (mm)})-16.61)^{2.9501}$

The resulting estimates were then used to calculate the average weight of the retained individuals of each species. Average weights were calculated for each respective "stock", as specified in the above equations (noting that catch and effort statistics for each of the 3 Inner Bay stocks of pink snapper is reported for all of those stocks combined in Zone 1). Fish lengths recorded from captures made in blocks that straddled these "stock" boundaries were excluded from calculations of average weight. Estimates of total landed catch weights for each indicator species in the assessment year, 2007/08, were then calculated by multiplying these average landed weights by the numbers of fish estimated to have been caught and landed from each "stock". Estimates of average landed weights and numbers used for these calculations are given in Table 6.1.5.

**Table 6.1.5.** Estimates of mean weight and number of fish landed by the recreational sector per indicator "stock" for the assessment year, 2007/08. Estimates for pink snapper for Zone 1 include 3 biological stocks for stock assessment: Denham Sound, Eastern Gulf and Freycinet, combined. *As no length data for this species were collected from the RFS, a corresponding estimate of catch (T) was not available.

| Species | Zones | Mean weight (g) | Standard error | Number of lengths | Number landed | Catch (T) |
|---|---|---|---|---|---|---|
| Pink snapper | 1 | 2,454 | 63.8 | 128 | 3,998 | 9.81 |
| | 2-7 | 2,600 | 46.6 | 423 | 8,212 | 21.35 |
| | **All** | n/a | n/a | 551 | 12,210 | **31.16** |
| Spangled emperor | 1-4 | 1,984 | 158.6 | 60 | 2,716 | 5.39 |
| | 5-7 | 1,968 | 71.8 | 180 | 12,404 | 24.41 |
| | **All** | n/a | n/a | 240 | 15,120 | **29.80** |
| Goldband snapper | All | - | - | 0* | 1,443 | - |

### 6.1.2.3 Charter catch and effort

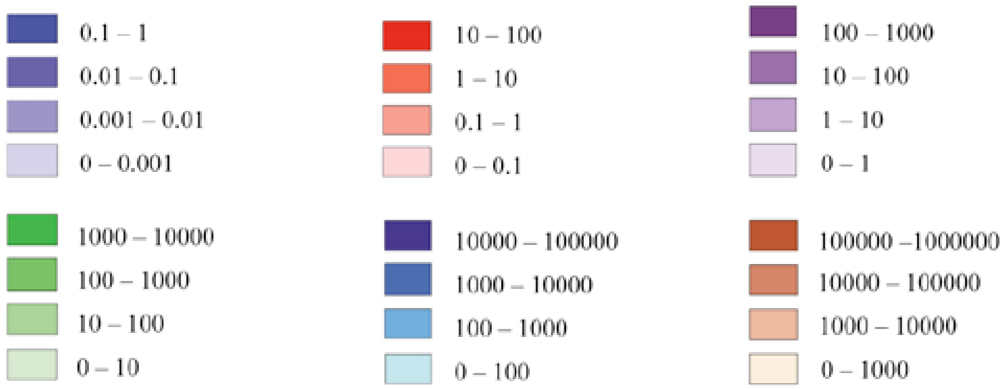
Charter C&E data were reported (via monthly returns) by 5 x 5 nm reporting blocks. Fish lengths (TL, cm) were not available for all catches, which were reported in numbers of individuals landed. As these catch data were similar in nature to those collected from the Recreational Fishing Survey (i.e., numbers and lengths of fish landed), calculations to estimate landed catch weights were consistent with those detailed in Section 6.1.2.2. Accordingly, estimates of average landed weights and numbers used for these calculations are given in Table 6.1.6.

**Table 6.1.6.** Estimates of mean weight and number of fish landed by the charter sector per indicator "stock" for the assessment year, 2007/08. Estimates for pink snapper for Zone 1 include 3 biological stocks for stock assessment: Denham Sound, Eastern Gulf and Freycinet, combined.

| Species | Zones | Mean weight (g) | Standard error | Number of lengths | Number landed | Catch (T) |
|---|---|---|---|---|---|---|
| Pink snapper | 1 | 1,977 | 68.7 | 82 | 1,124 | 2.22 |
| | 2-7 | 2,269 | 33.0 | 606 | 8,443 | 19.16 |
| | **All** | n/a | n/a | 688 | 9,567 | **21.38** |
| Spangled emperor | 1-4 | 2,477 | 56.9 | 261 | 1,115.6 | 2.76 |
| | 5-7 | 2,262 | 29.3 | 817 | 2,346.4 | 5.31 |
| | **All** | n/a | n/a | 1078 | 3,462.0 | **8.07** |
| Goldband snapper | **All** | 3,197 | 53.0 | 110 | 1,649 | **5.27** |

### 6.1.2.4 Keys for mapping catch and effort

To ensure data confidentiality, information on the maps are presented as high, medium, low and very low based on logarithmic scales as shown below. The different colour schemes have been used so that data can be presented on different scales as appropriate (i.e. 0-0.1, 0-100, 0-1,000, 0-10,000, 0-100,000 and 0-1,000,000).




## 6.1.3 Results and discussion

### 6.1.3.1 Fishing effort

Commercial fishing effort in Zones 1 to 4 was dominated by 'wetline' prior to the introduction of management of the SBSF in 1987 (Figs. 6.1.4, 6.1.5, 6.1.6). A 'spawning season closure' was implemented in July 1986 and 1987 in an effort to limit the snapper catch during the peak season, that saw a shift in commercial trap and line fishing effort to north of the northern boundary of that fishery at that time (23°30'S; Moran *et al.* 1993). Since that time effort levels in the SBSF and line fishing operations more generally have been more tightly managed and remained relatively stable or decreased gradually in Zones 1 and 2 (Figs. 6.1.4., 6.1.5.). However, in Zone 3 effort levels were observed to increase from 1999/00 to 2002/03, and reflect a shift toward the targeting of deeper water species such as goldband snapper and ruby snapper (Fig. 6.1.6.). Effort has since progressively decreased following reductions in pink snapper TACC (by 40% in 2003/04) and concerns over the sustainability of fishing for goldband snapper (M. Moran pers. comm.). Importantly, the majority of effort ascribed to Zone 3 (deeper than 250 m) by spatial apportionment is likely to have actually been expended in the deeper, further offshore blocks of Zone 2, coincident with the shallower habitat occupied by the goldband and ruby snappers targeted.

In Zones 5-7, commercial fishing effort was dominated by 'wetline', with handline and dropline being the predominant methods (Figs. 6.1.7, 6.1.8). Fish trapping became popular in the mid-1980s in this area following management restrictions on trapping elsewhere within the SBSF (Moran et al. 1993). The overall level of fish trapping declined significantly following the commencement of the limited entry Pilbara Trap Fishery in May 1992 (Pilbara waters; Fig. 6.1.7.). Prior to this, however, a gradual decline in commercial line fishing effort was also apparent from 1984/85 to 1991/92 in Zones 5 and 6, and from 1987/88 to 1991/92 in Zone 7. Moran *et al.* (1993) reported that a change in the spatial distribution of commercial fishing effort in north-western Australia from 1987 to 1992, which could offer some explanation for this trend. They reported that in 1987 commercial line fishing was concentrated primarily in waters off Geraldton and trap fishing around the North West Cape (i.e., Zones 5 and 6) and by 1992 commercial fishing was more wide-spread across north western Australia, with high catches being made by the commercial trawl fishery off Point Samson (i.e., to the north-east of the Gascoyne). A reduction in commercial effort was observed from 22°S to 24°S (i.e., mainly Zones 5 and 6) to be concomitant with an increase in effort off Shark Bay (i.e., mainly Zone 2), with changing management rules for different commercial fisheries complicating the interpretation of such patterns (Moran *et al.* 1993).

There is a relatively low amount of effort shown for the Pilbara Trap fishery in Figure 6.1.7 because the majority of fishing effort for this fishery takes place to the north east of the Gascoyne Bioregion.

Effort data presented for Zone 7 closely reflects the trends observed for Zones 5 and 6 combined, and it is likely that the majority of this effort ascribed by spatial apportionment to Zone 7 was actually expended in Zone 6, which contained greater quantities of habitat typically occupied by the demersal scalefish species that were targeted.

The spatial pattern of commercial fishing effort in these fisheries has changed little from 2001/02 to 2006/07 (Fig. 6.1.9.). Despite a substantial decrease in fishing effort (hundreds of days) in the block immediately north of Exmouth Gulf, and to a lesser extent, the decrease in effort for the block east of Bernier, Dorre and Koks Islands (and directly offshore from Carnarvon), all other observed changes were trivially small. The decrease in effort to the north of Exmouth Gulf likely reflects the Prohibition on Fishing by Line from Fishing Boats (Pilbara Waters) Order 2006 implemented on 15 August 2006, with exceptions given to nine vessels, but those were restricted to commercial line fishing during a five-month period each year. The small amount of fishing activity by state-licensed vessels recorded within the Commercial Fishing Exclusion Zone in 2001/02 represents residual commercial fishing that was in the process of being phased out following the Offshore Constitutional Settlement (OCS) in 1995; prohibition on state-licensed commercial fishing activities from the limit of state waters (3 nm from the coast) to the limit of Commonwealth waters (200 nm from the coast).

Both recreational and charter fishing effort for Zone 1 have declined from 1998/99 to 2007/08 and from 2002/03 to 2007/08, respectively (Fig. 6.1.10**.**). Recreational fishing effort for all other zone groupings, however, was higher in 2007/08 than in 1998/99 (Fig. 6.1.11.). Charter fishing effort for zones 2-4 was relatively stable and fluctuating from 2002/03 to 2007/08 (Fig. 6.1.11). In zones 5-7, charter fishing effort was highest in 2002/03 before almost halving in 2003/04, then fluctuating at approximately that level through to 2007/08. In 2005/06 and 2006/07 a slight decline in effort for zones 2-4 was matched by a slight increase in effort for the adjacent zones 5-7 (Fig. 6.1.11).

There was a conspicuous contraction in the spatial distribution of charter fishing effort from 2002/03 to 2007/08 in most areas (Fig. 6.1.13). Conversely, spatial information obtained from boat-based recreational fishers in 2007/08 indicated an expansion of recreational fishing effort out from most interview ramp locations from 1998/99 to 2007/08 (Fig. 6.1.14). Most notable expansions in recreational fishing activity were about the North-West Cape, out from Coral Bay (Point Maud) and out to the islands offshore from Carnarvon (Fig. 6.1.14).

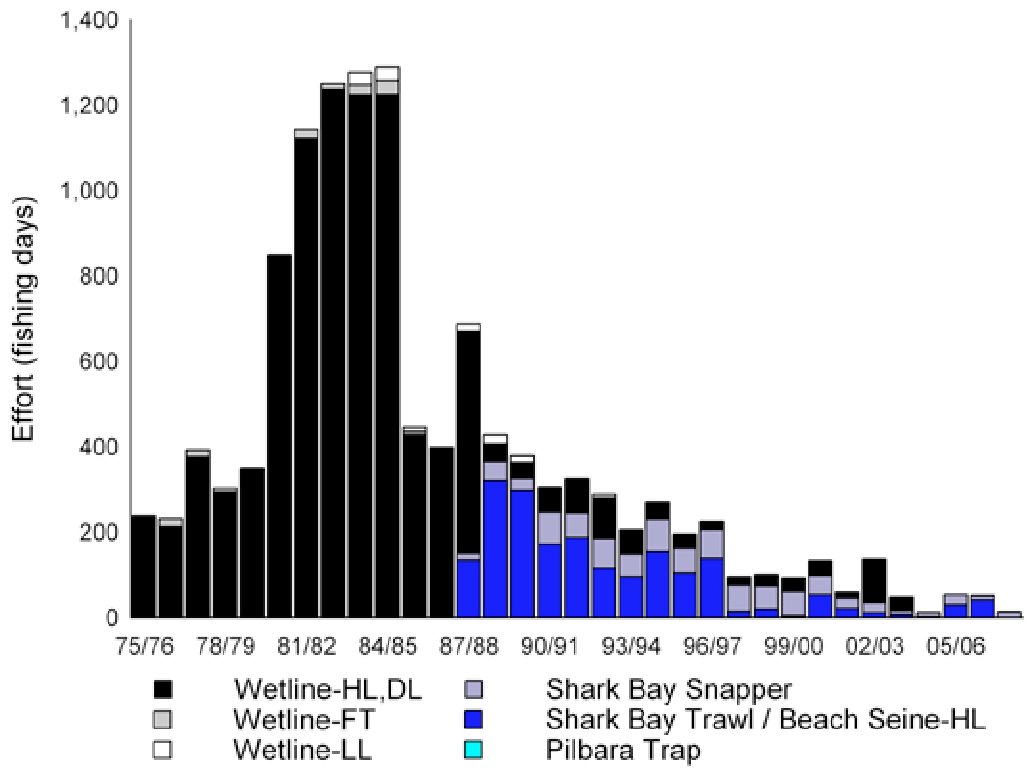



**Figure 6.1.4.** Commercial fishing effort (trap and line) in Zone 1.

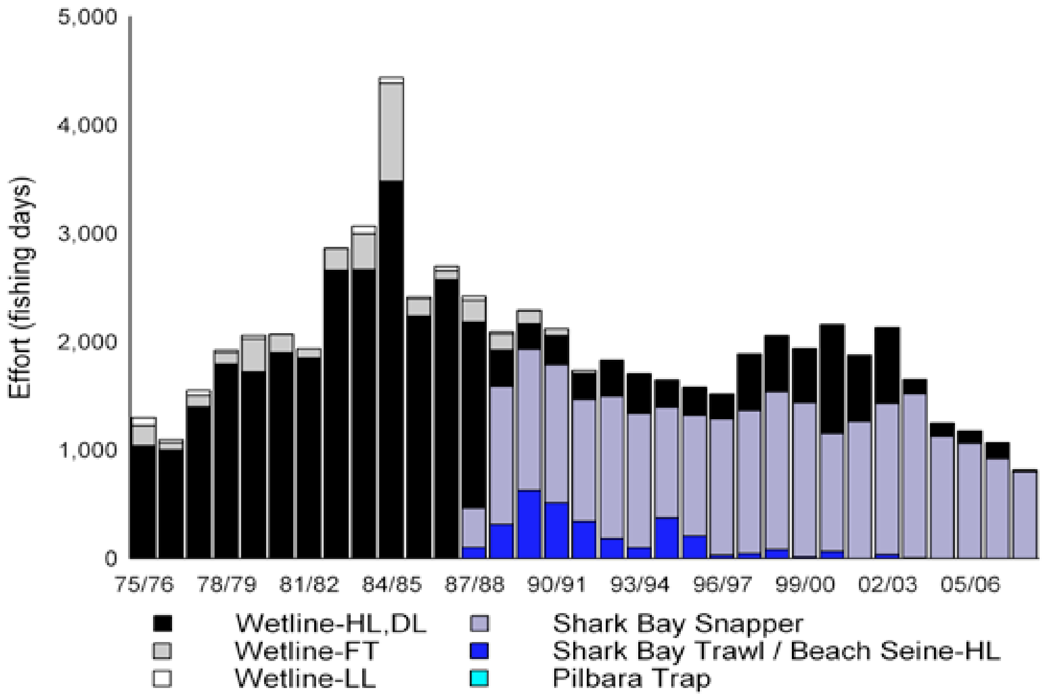



**Figure 6.1.5.** Commercial fishing effort (trap and line) in Zones 2 and 4 combined.

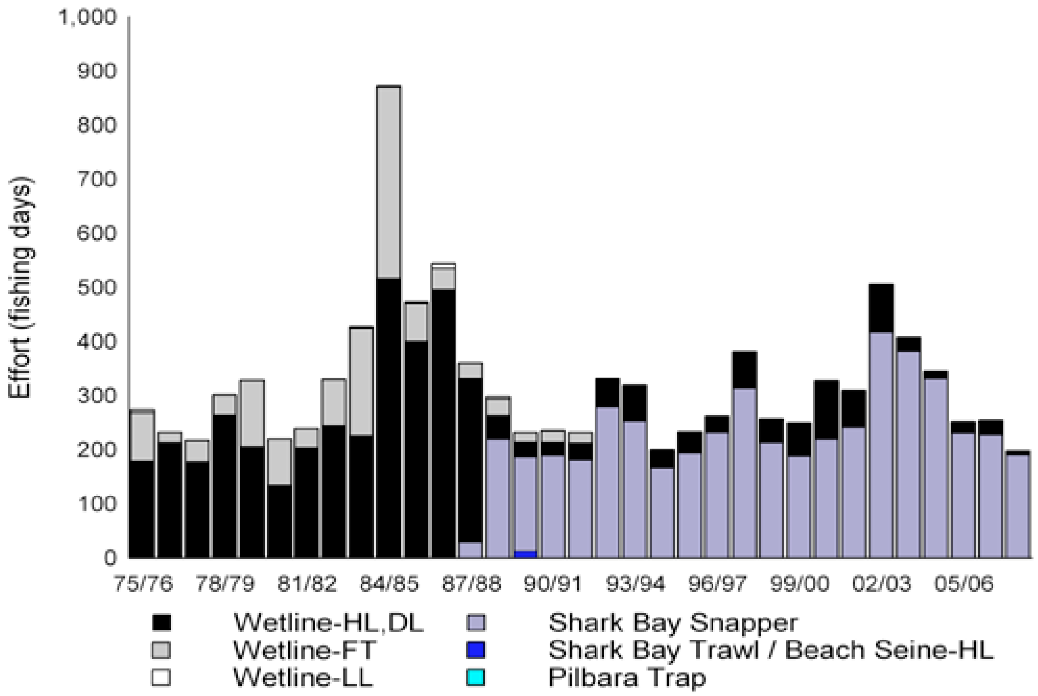



**Figure 6.1.6.** Commercial fishing effort (trap and line) in Zone 3.

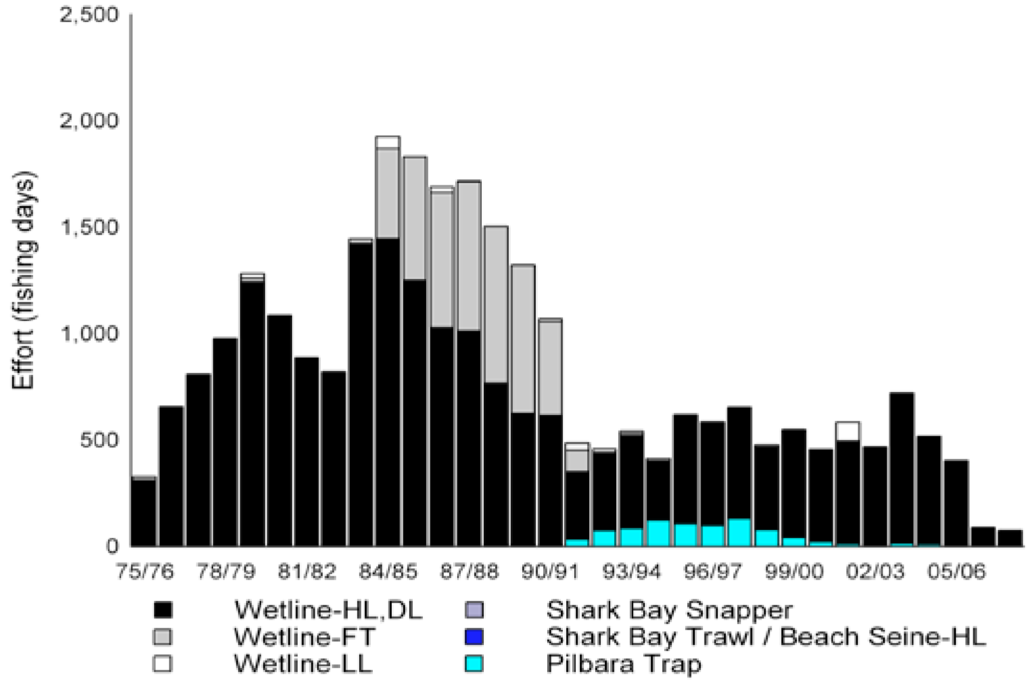



**Figure 6.1.7.** Commercial fishing effort (trap and line) in Zones 5 and 6 combined.

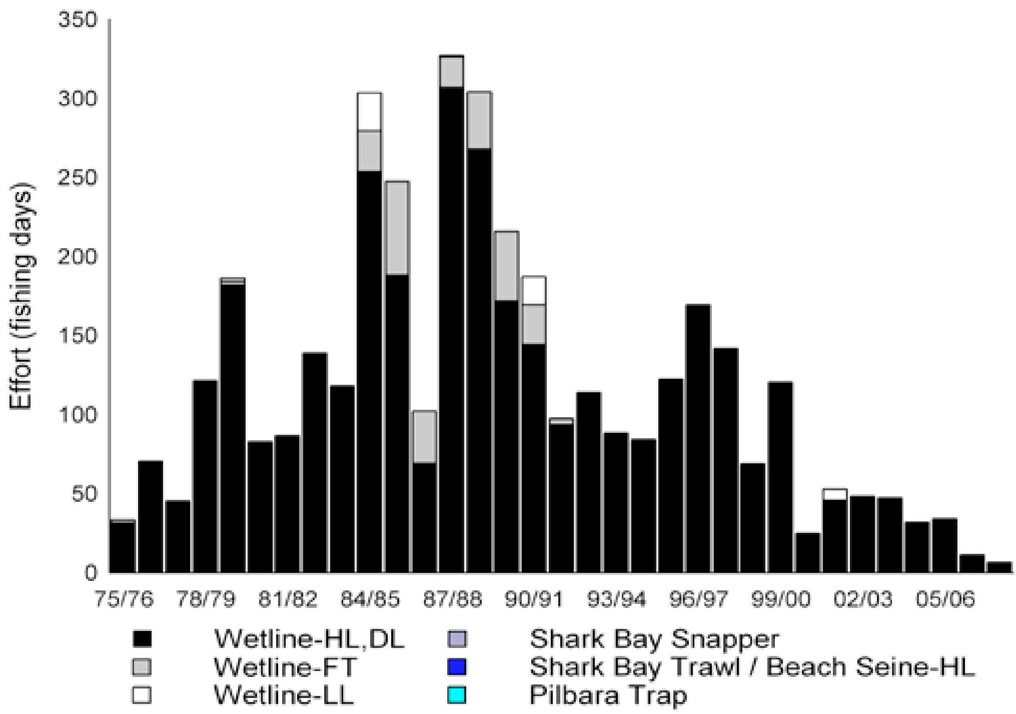
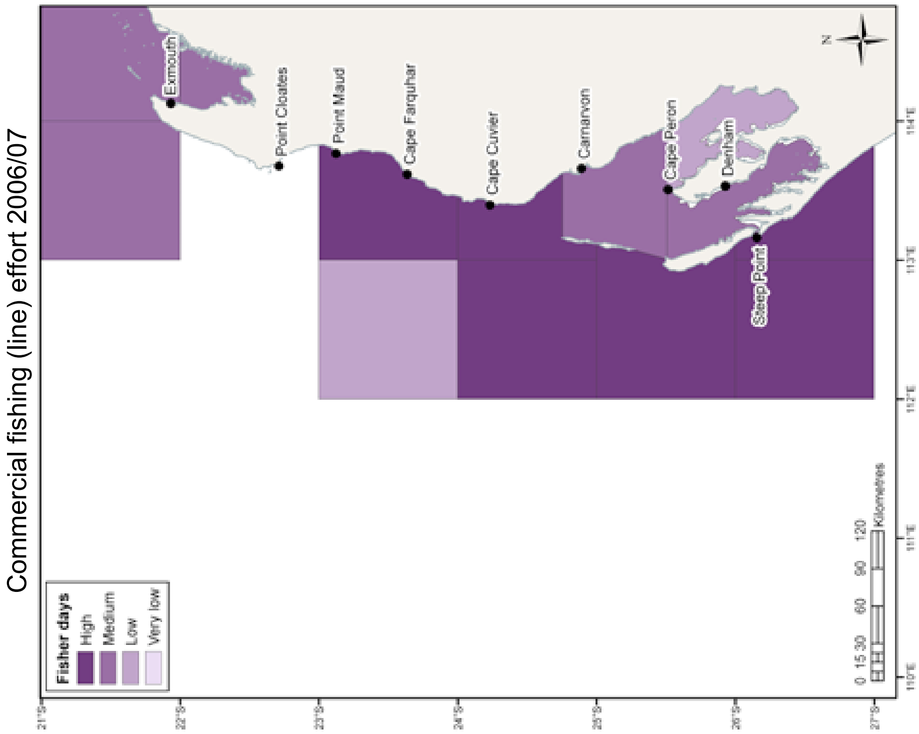



**Figure 6.1.8.** Commercial fishing effort (trap and line) in Zone 7.



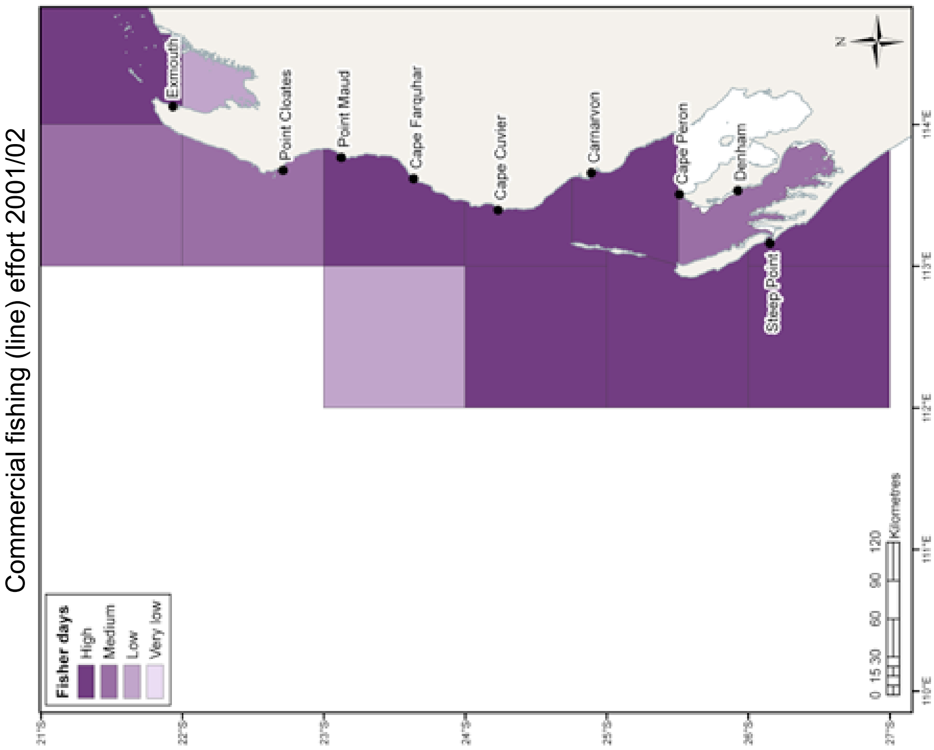




**Figure 6.1.9.** Commercial effort (line fishing only) in the Gascoyne Coast Bioregion for 2001/02 (bottom) and 2006/07 (top).

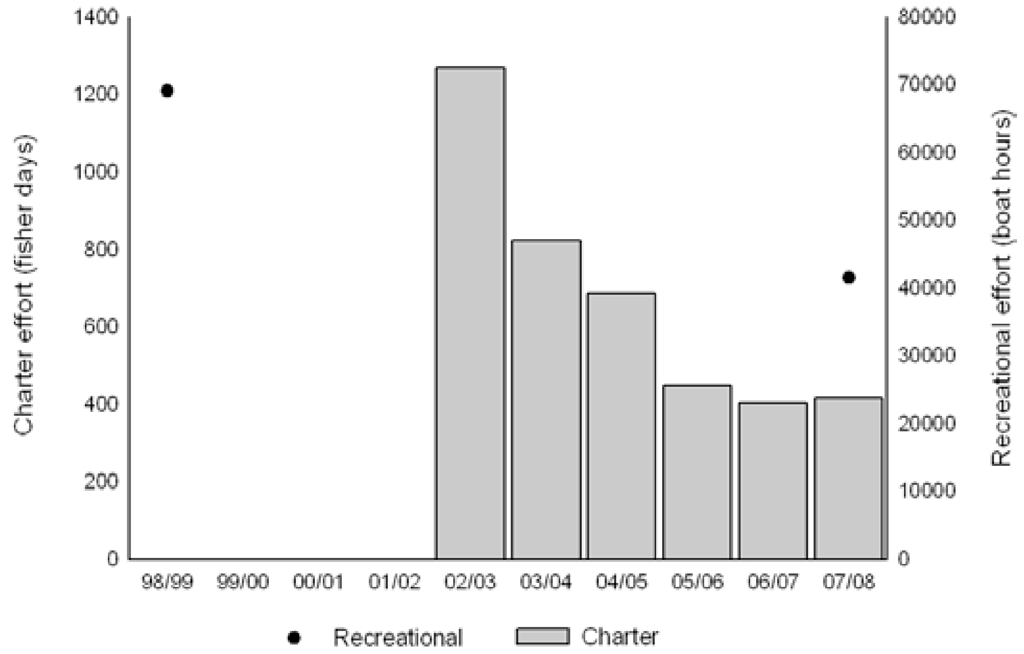



**Figure 6.1.10.** Recreational and charter fishing effort in Zone 1.

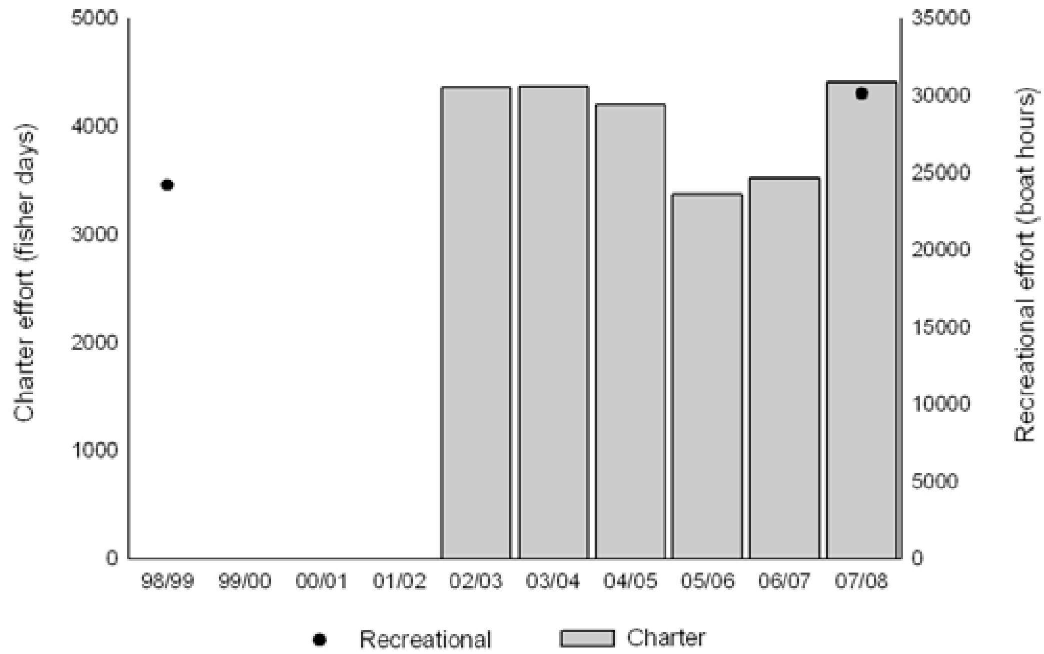



**Figure 6.1.11.** Recreational and charter fishing effort in Zones 2 to 4 combined.

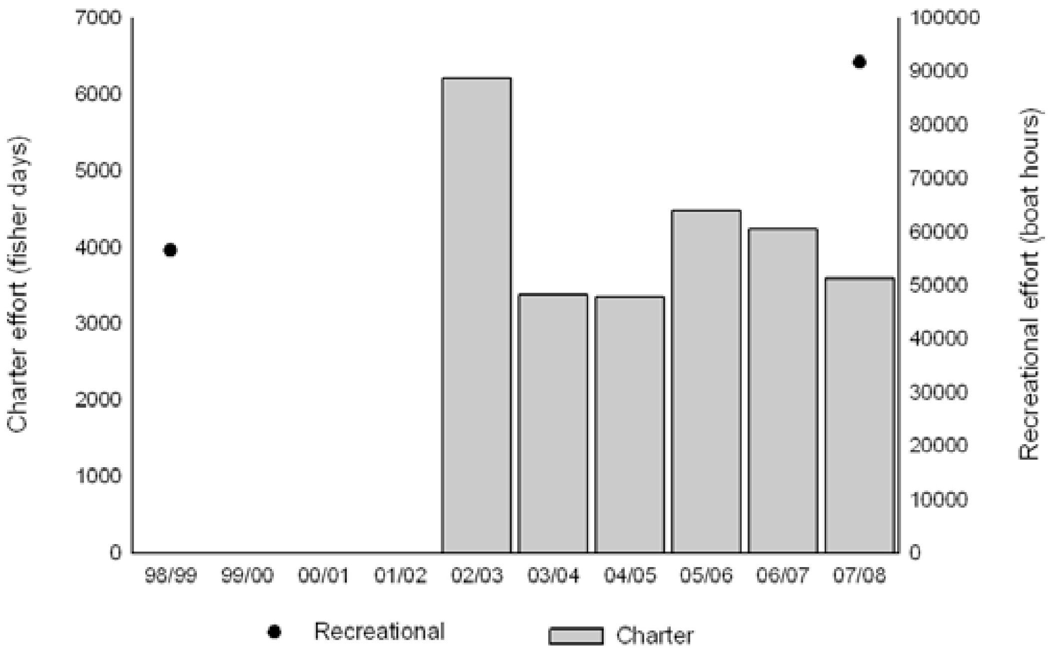
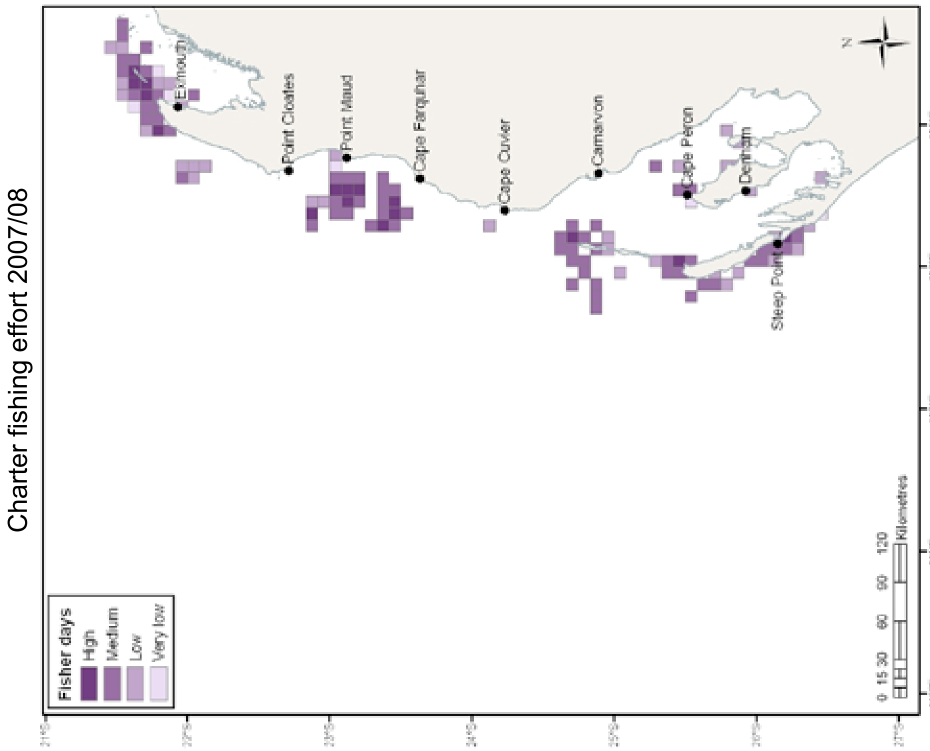



**Figure 6.1.12.** Recreational and charter fishing effort in Zones 5 to 7 combined.



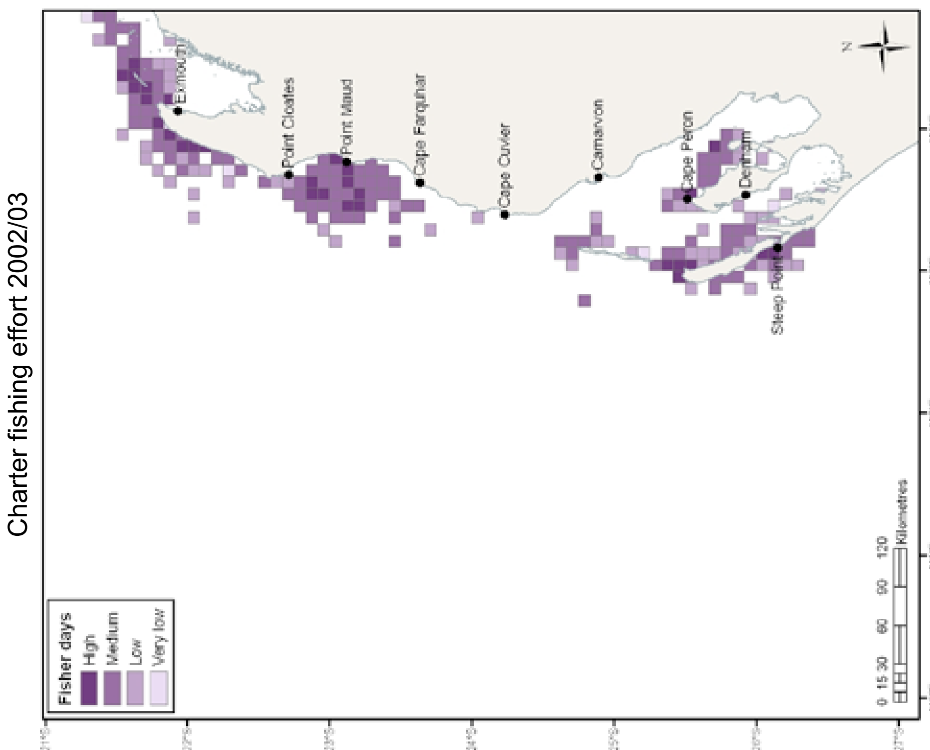
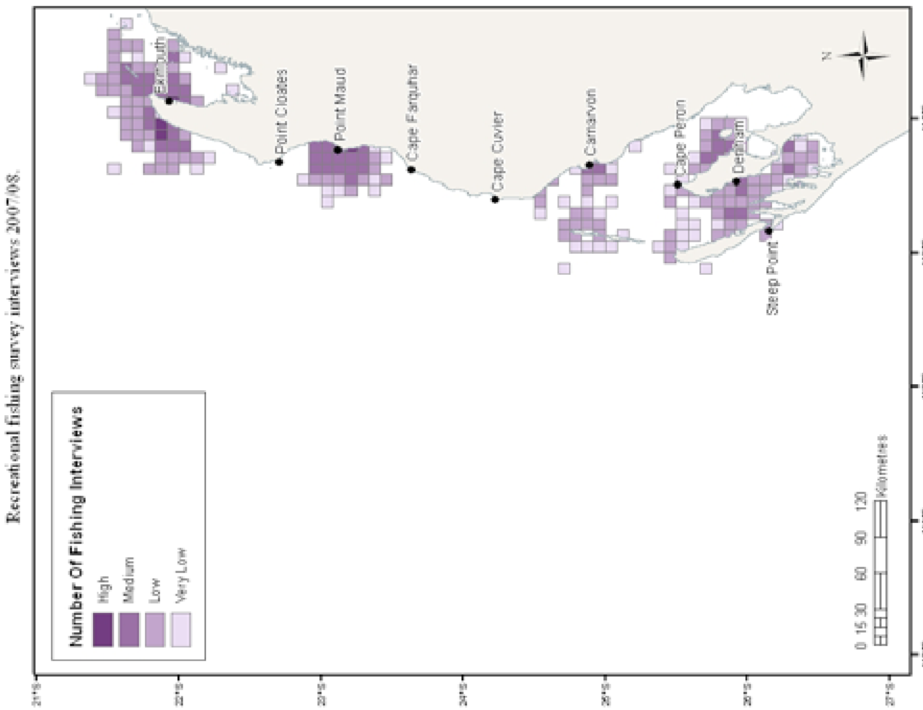




**Figure 6.1.13.** Charter fishing effort in the Gascoyne Coast Bioregion for 2002/03 (bottom) and 2007/08 (top).



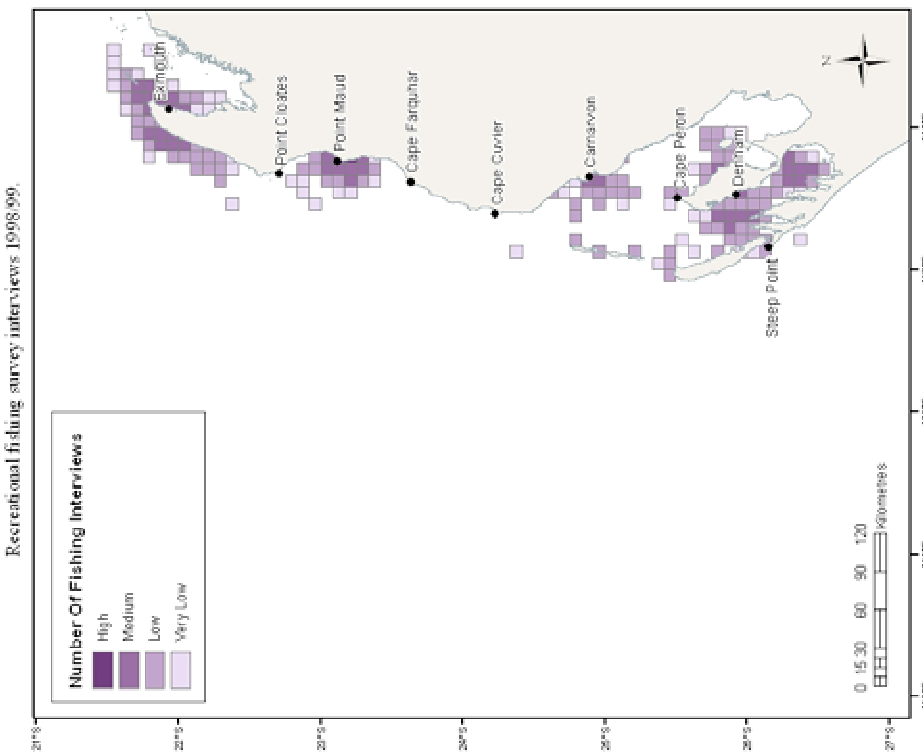




**Figure 6.1.14.** Relative frequency of fishing locations in recorded from interviews with recreational boat-based fishers in the Gascoyne Coast Bioregion during 1998/99 (bottom) and 2007/08 surveys (top).

### 6.1.3.2 Pink snapper catch

Commercial vessels caught large quantities of pink snapper in the Gascoyne off Shark Bay prior to 1975 (see Bowen 1961); the commercial catch increased from 216 t in 1952 to 741 t in 1959 before declining sharply to less than 100 t by 1970. Catches increased again through the late 1970s and mid-1980s, rising sharply from 423 t in 1976 to an all-time peak of 1287 t in 1985 (Figure 6.1.15). The creation of the SBSF saw pink snapper catches decline to 646 t in 1987, and then remain relatively stable at ca. 450-550 t from the late 1980s through to the early 2000s. Between 1987 and 2001, the SBSF was managed using individual transferable quotas that only applied during the peak season (May-August) and a nominal TACC of 550 t. Since 2001, the SBSF has been managed by quota all-year-around, with an explicit TACC set initially at 564 t. Catches declined between 2003/04 and 2007/08 following reductions in the TACC in 2004 (by 40% to 338 t) and in 2007 (to 297 t in April, and, to 277 t in September).

Most of the commercial pink snapper catch 1975-2008 came from waters within Zone 2 (Figure 6.1.15). The SBSF has operated in proscribed waters (between 26 deg 30 min S to 23 deg 34 min S) since 1987. Historically, most of the catch (70-80%) has been taken during winter months from inshore reefs off Dorre, Bernier and Dirk Hartog Islands (Figure 6.1.16). Less commercial snapper fishing has occurred in Zone 1 although a small number of SBSF vessels were allowed to fish in Denham Sound up to 1996. There was little change in the spatial distribution of commercial catches of pink snapper between 2001/02 and 2006/07 (Figure 6.1.16).

The numbers of pink snapper caught and kept by recreational fishers fishing from charter vessels increased from 2002/03 to 2003/04 and then declined to return to the pre-2004 level in 2006/07, before increasing slightly in 2007/08 (Figure 6.1.17). As with commercial fishing, nearly all the charter catch was taken from Zones 2, 3 and 4 (Figure 6.1.17) with effort focussed on similar grounds to commercial operations. Some catches also came from waters north of Caper Farquhar, off Point Maud, that were not accessible to commercial vessels (Figure 6.1.18).

The estimated number of pink snapper caught by recreational fishers from private boats for the entire Gascoyne Coast Bioregion in 2007/08 was less than half the number estimated in 1998/99 (Figure 6.1.15). There was a spatial shift (between zones) in catches between the surveys, in response to management changes introduced during the period 1996-2003. In 1998/99, approximately half the recreational pink snapper catch came from oceanic waters (Zone 2) and half from inner gulf waters (Zone 1). Regulations to protect inner gulf stocks that were implemented from 1996/97 onwards, in particular the introduction of TAC-based management in 2003[*] were reflected in a decline in the overall recreational pink snapper catch in the inner gulfs (Zone 1). A similar number of pink snapper were caught from waters outside of Shark Bay in 1998/99 and 2007/08 (Fig. 6.1.15).

Although a similar number of pink snapper were reported, there was some evidence of a shift in capture locations outside of Shark Bay, from 1998/99 to 2007/08, with more catches reported from blocks further offshore from Carnarvon, and from areas north of Shark Bay, in 2007/08 than in 1998/99 (Fig. 6.1.20). This spatial shift in catch locations for pink snapper corresponds to the general expansion of fishing effort between surveys shown in Figure 6.1.14.

* Recreational boats were encouraged to fish for pink snapper in oceanic waters, to relieve pressure on the Denham Sound stock, through introduction of exemption based system administered through Denham Fisheries Office, that allowed vessels to land more fish at Denham than were permitted under inner gulfs regulations (this exemption scheme was discontinued in 2009).

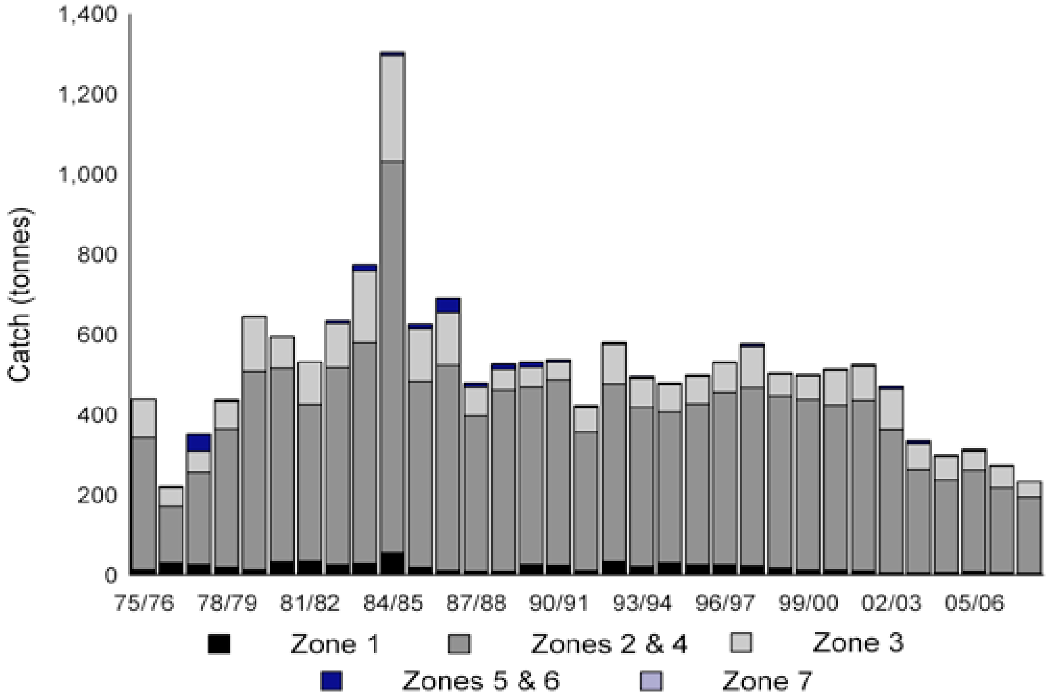
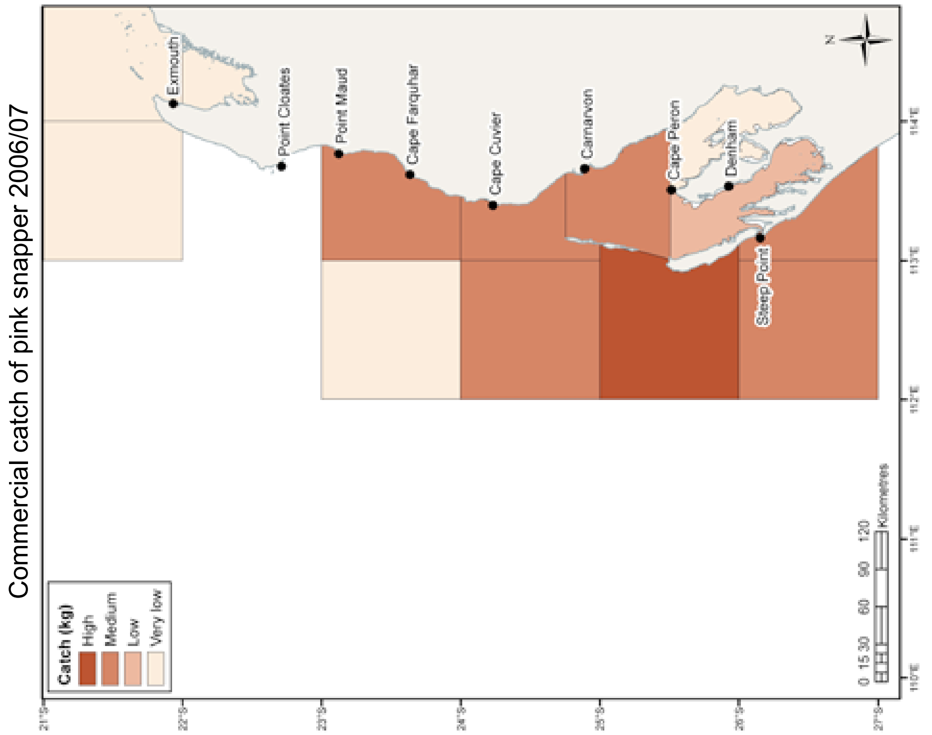



**Figure 6.1.15.** Commercial catch of pink snapper (all gears) in Gascoyne Coast Bioregion 1975/76-2007/08 by zone. Note: apportionments of catch to zones is approximate and based on area for boundary blocks.



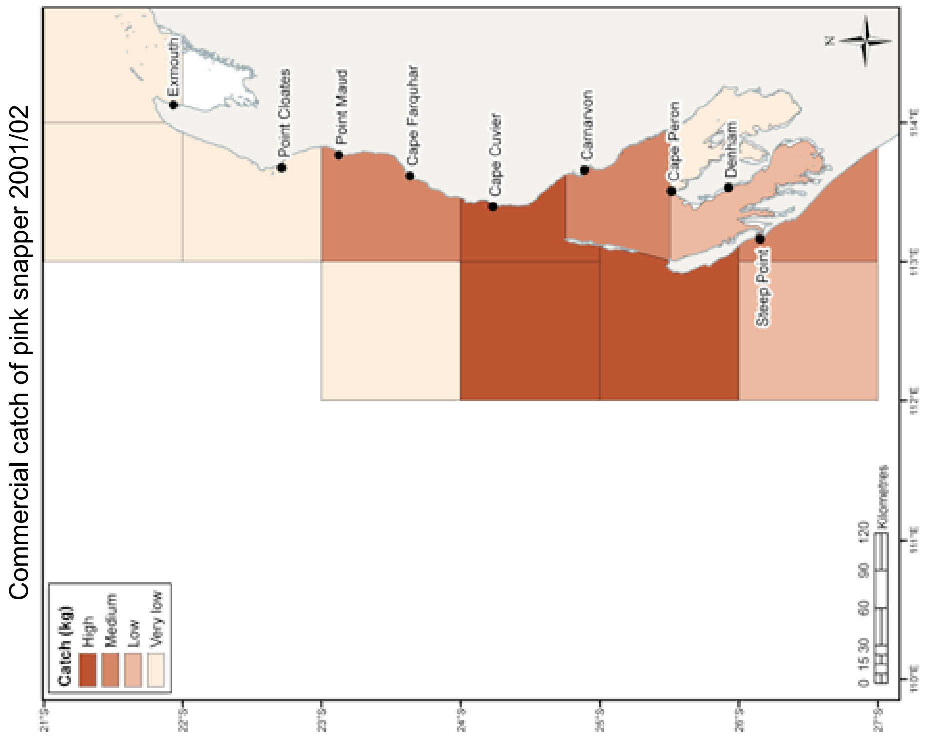




**Figure 6.1.16.** Commercial catch of pink snapper (all gears) in the Gascoyne Coast Bioregion for 2001/02 (bottom) and 2006/07 (top).

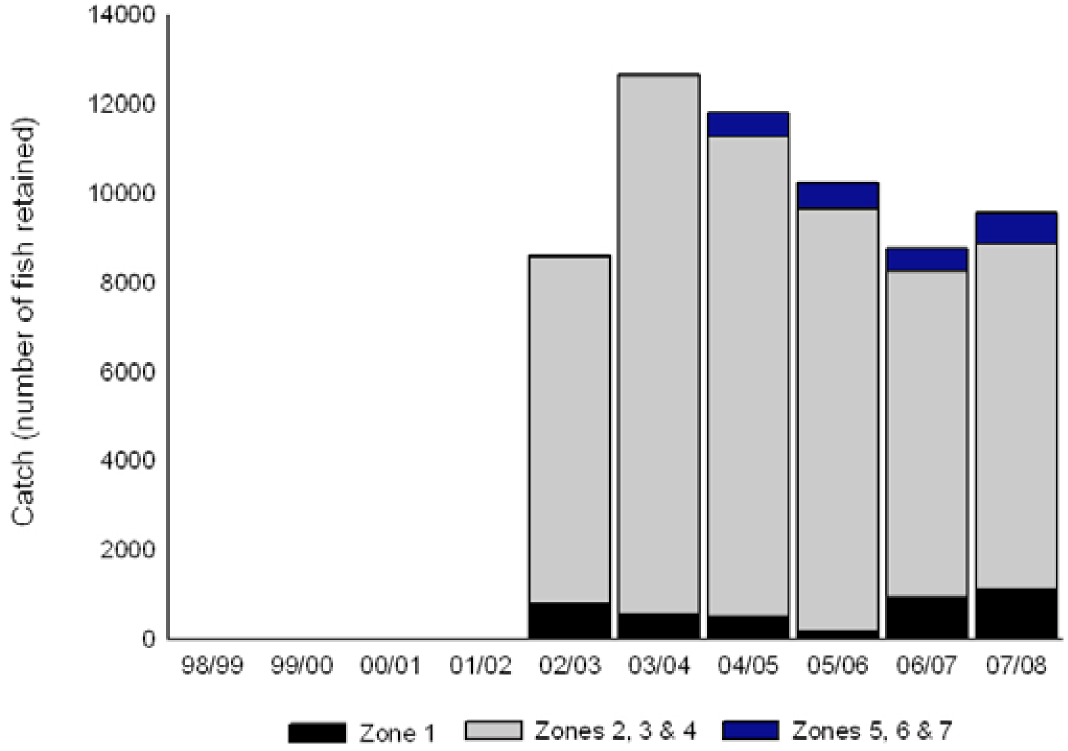
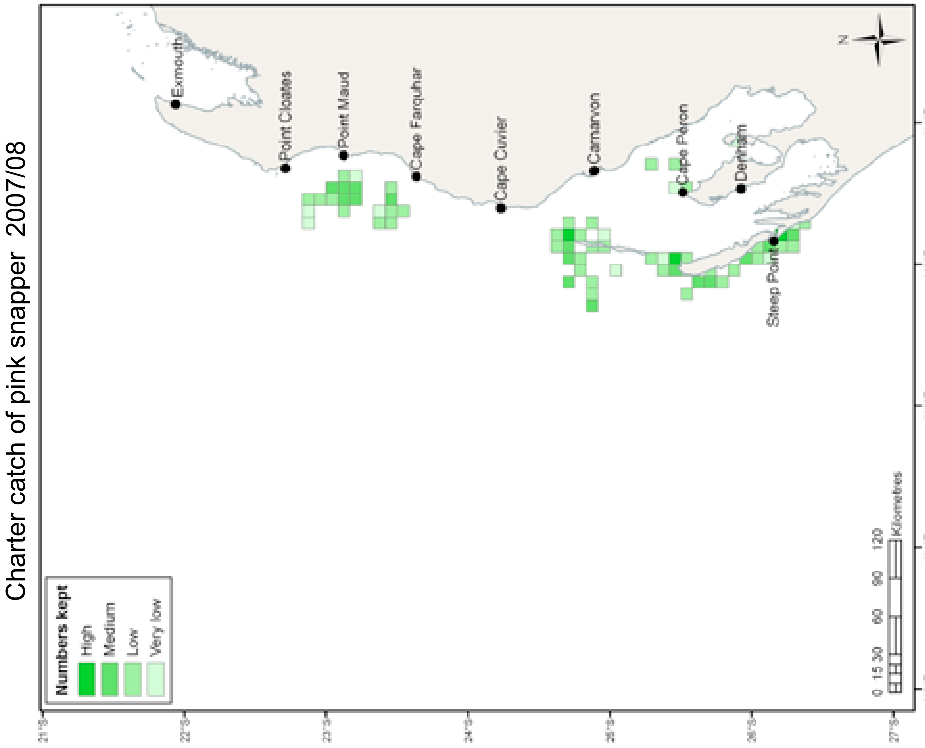



**Figure 6.1.17.** Charter catch of pink snapper in the Gascoyne Coast Bioregion.



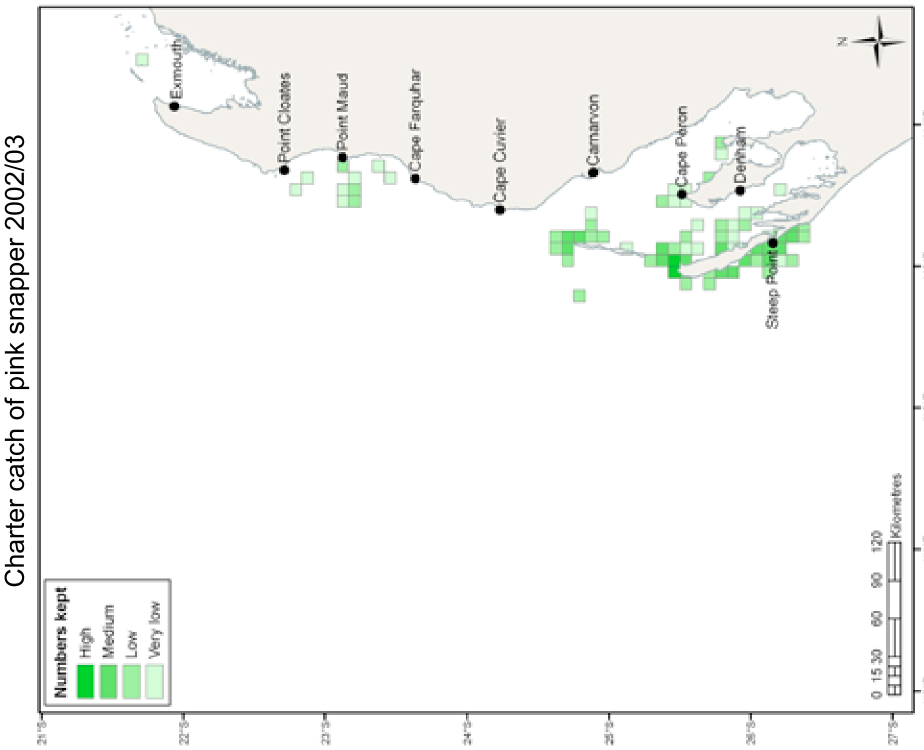




**Figure 6.1.18.** Charter pink snapper catch in the Gascoyne Coast Bioregion for 2002/03 and 2007/08.

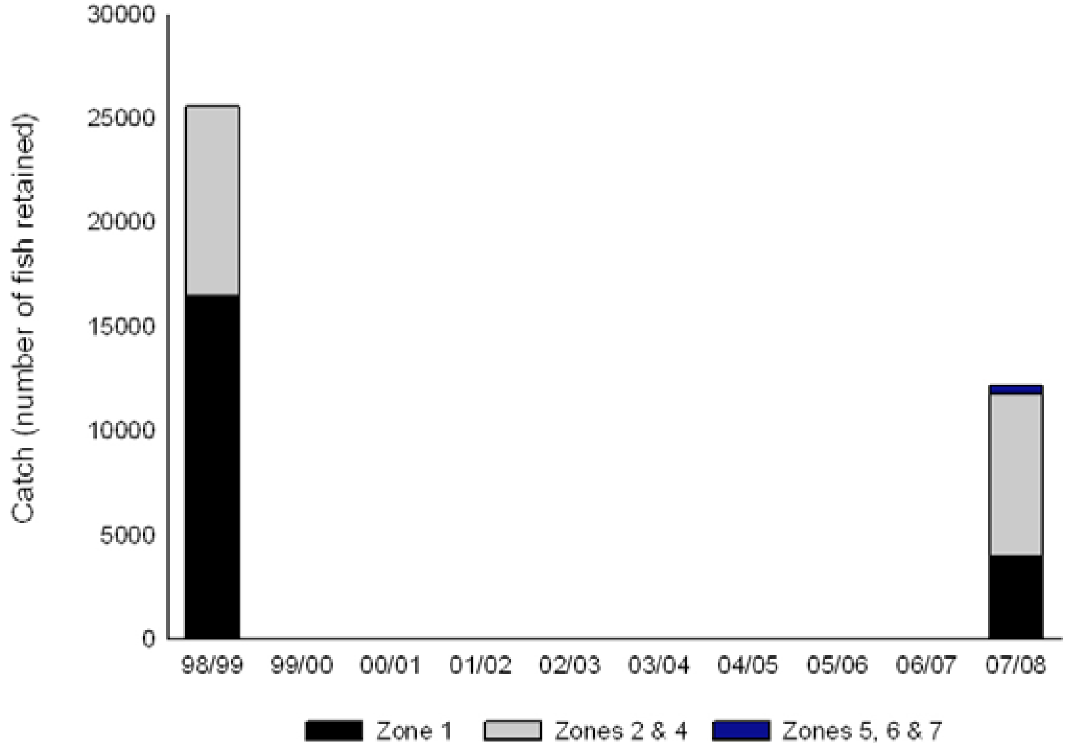
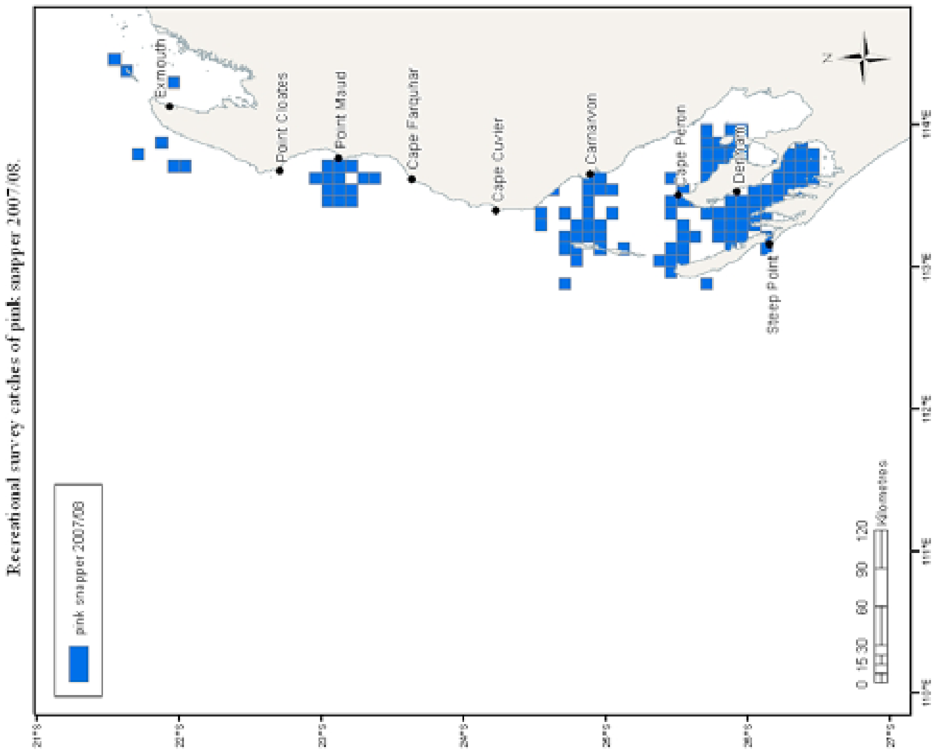



**Figure 6.1.19.** Estimated recreational catch of pink snapper in the Gascoyne Coast Bioregion.



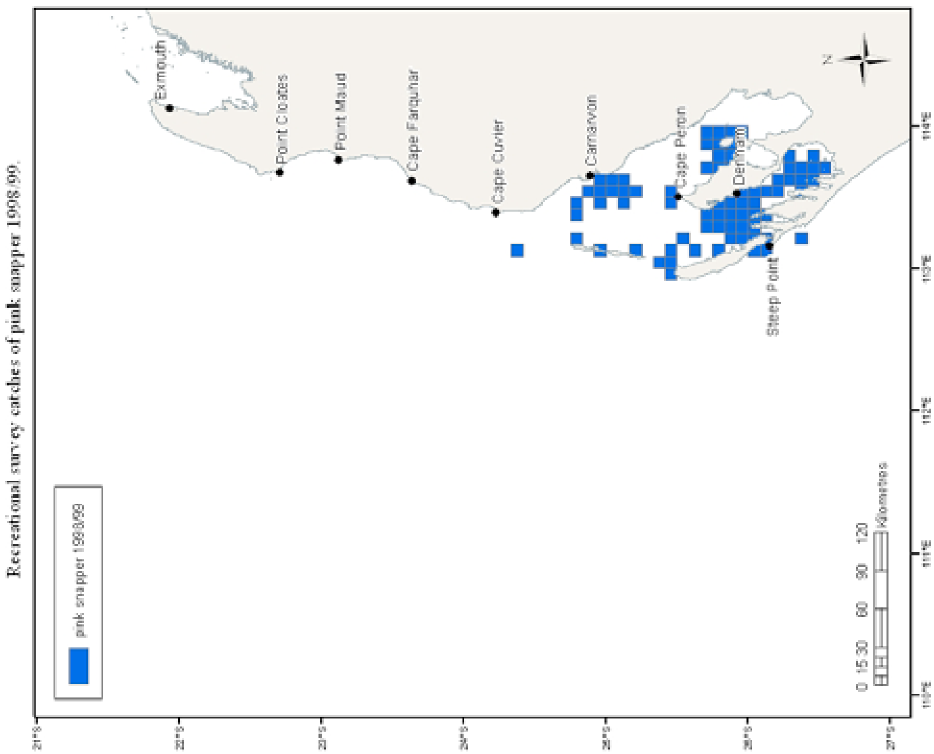




**Figure 6.1.20.** Capture locations of pink snapper recorded from interviews with recreational boat-based fishers in the Gascoyne Coast Bioregion during 1998/99 (bottom) and 2007/08 surveys (top).

### 6.1.3.3 Spangled emperor catch

The historical commercial catch of spangled emperor (North West Snapper) in the Gascoyne was relatively stable from 1975/76 to 1983/84 before increasing substantially from the mid 1980s to the early 1990s (Fig. 6.1.21.). This period of elevated catches, primarily from Zone 6, coincided with an increase in trap and line fishing west of 114ºE and north of the SBSF (Moran *et al.* 1993). Elevated catches in Zone 2 are also conspicuous for that period, which coincided with a huge increase in effort in the SBSF, resulting in increased levels of bycatch of lethrinid species (including spangled emperor) during that period (Fig. 6.1.21.; Moran *et al.* 1993). Thereafter the levels of catch declined following increased levels of regulation on commercial fishing mainly associated with the commencement of the Pilbara Trap fishery in 1992, the phasing out of commercial fishing in the Commercial Exclusion Zone from 1995, and subsequent limitations on fishing effort for bycatch and byproduct species in that fishery. The commercial catch of spangled emperor has also likely declined as a result of a shift in targeting practices by commercial operators to more valuable deeper-water species such as goldband snapper since the early 2000s.

The spatial distribution of commercial catches of spangled emperor appears to have changed little from 2001/02 to 2006/07, with the cessation of catches previously observed from the Commercial Exclusion Zone out from Ningaloo in 2006/07, compared to low catches in 2001/02, and slightly lower levels of catch observed in a number of other blocks (Fig. 6.1.22**.**). Historically, though, the relatively high levels of catch observed from the mid 1980s to early 1990s were primarily occurring in the Pilbara waters (north of North West Cape and Exmouth Gulf) and in the Commercial Exclusion Zone (outside of the Ningaloo Marine Park). For instance, in 1987/88 and 1988/89 the highest catches of spangled emperor were made from the coastal CAES block in the Exclusion Zone and in 1988/89 over 50 tonnes was caught from that block, mostly by fish trapping.

The number of spangled emperor caught and retained by charter fishers was highest in2002/03 and then declined to become relatively stable and fluctuating from 2003/04 to 2007/08 (Fig. 6.1.23). The majority were caught from zones 5-7, followed by catches made in zones 2-4, with a negligible number caught from zone 1. Most of the charter catches of spangled emperor were made west and northeast (Muiron Islands) of the North West Cape, west and southwest of Point Maud, to the north of Koks and Dirk Hartog Islands, and about Steep Point (Fig. 6.1.24.). There is a clear contraction in the spatial distribution of catches made in 2007/08 compared to 2002/03 (concomitant with the contraction in fishing effort noted in Section 6.1.3.1 above), with conspicuously fewer catches coming from the areas south of Point Cloates and west of North West Cape in 2007/08 than in 2002/03 (Fig. 6.1.24.).

The total estimated number of spangled emperor caught and retained by recreational fishers from the Gascoyne was slightly lower in 2007/08 than it was in 1998/99 (Fig. 6.1.25.). Most of this decline, however, was observed for zones 2 and 4, with the 2007/08 catch from those zones being only 66.1% of the 1998/99 catch, in numbers of fish. The estimated number of spangled emperor caught and kept by recreational fishers from zones 5-7 was very similar among surveys, with the number in 1998/99 being 99.86% of the number estimated for 2007/08. The estimated catch from zone 1 was negligible (Fig. 6.1.25).

Maps of block locations for captures of spangled emperor reported by recreational fishers indicate an expansion of the areas from which spangled emperor were caught from 1998/99 to 2007/08 (Fig. 6.1.26). Most of the new capture block locations for spangled emperor in 2007/08 were in areas further offshore from: North West Cape, Coral Bay (Point Maud), and Carnarvon (i.e., around Bernier, Dorre and Koks Island), than reported in 1998/99. This spatial shift in catch locations for spangled emperor corresponds to the general expansion of recreational fishing effort between surveys shown in Figure 6.1.14.

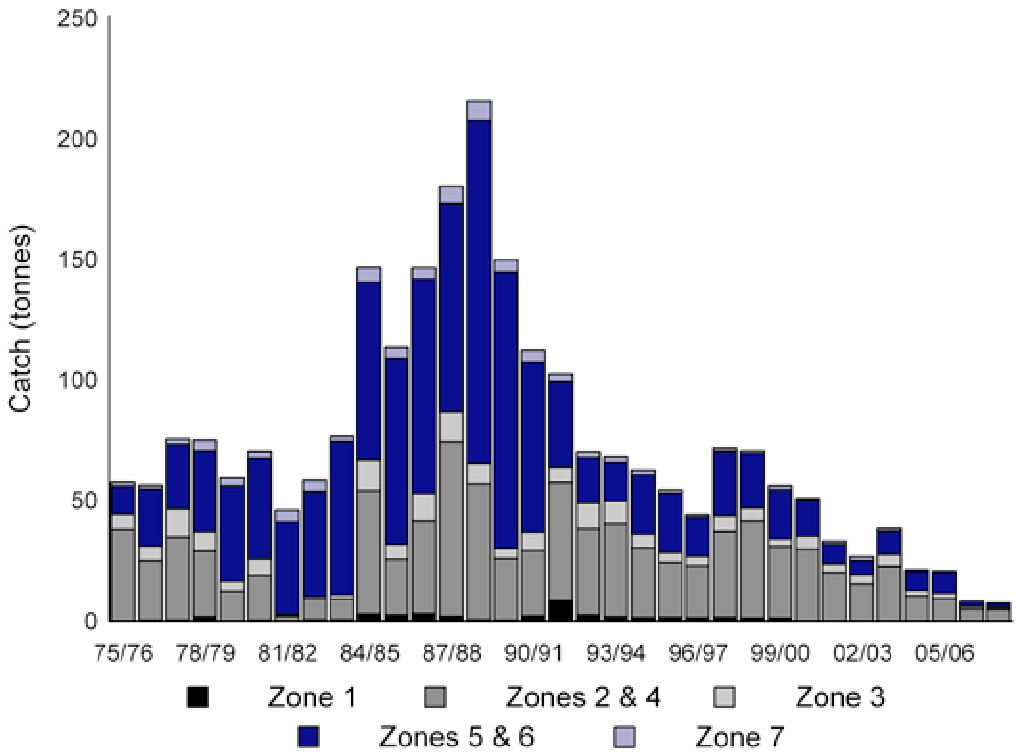
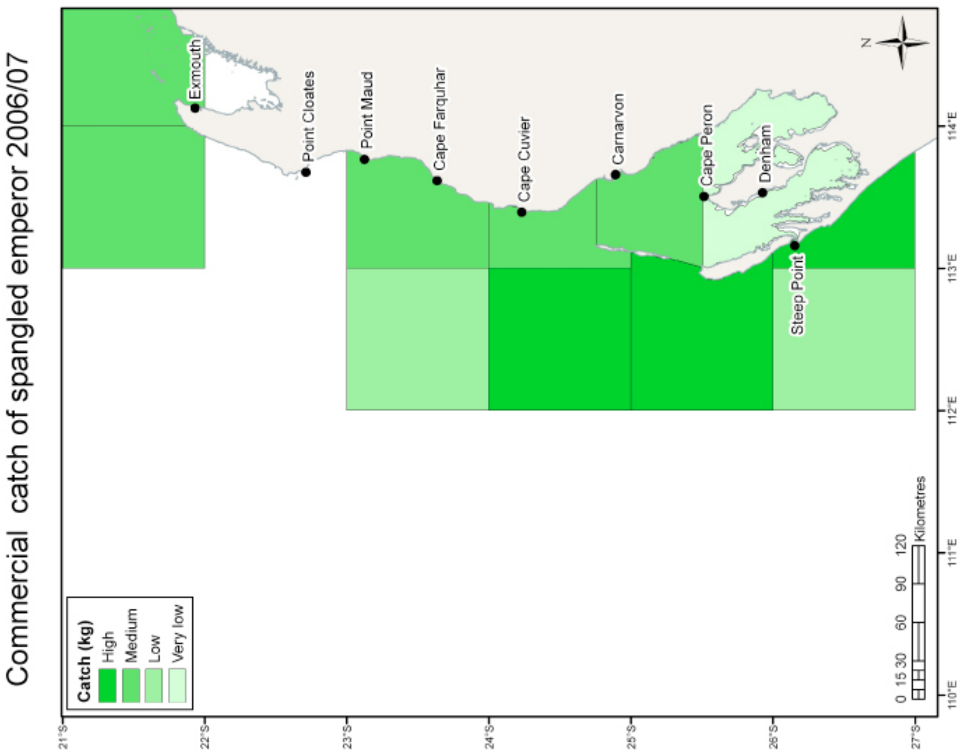



**Figure 6.1.21.** Commercial catch of spangled emperor (all gears) in each zone. Note: apportionments of catch to zones is approximate and based on area for boundary blocks.



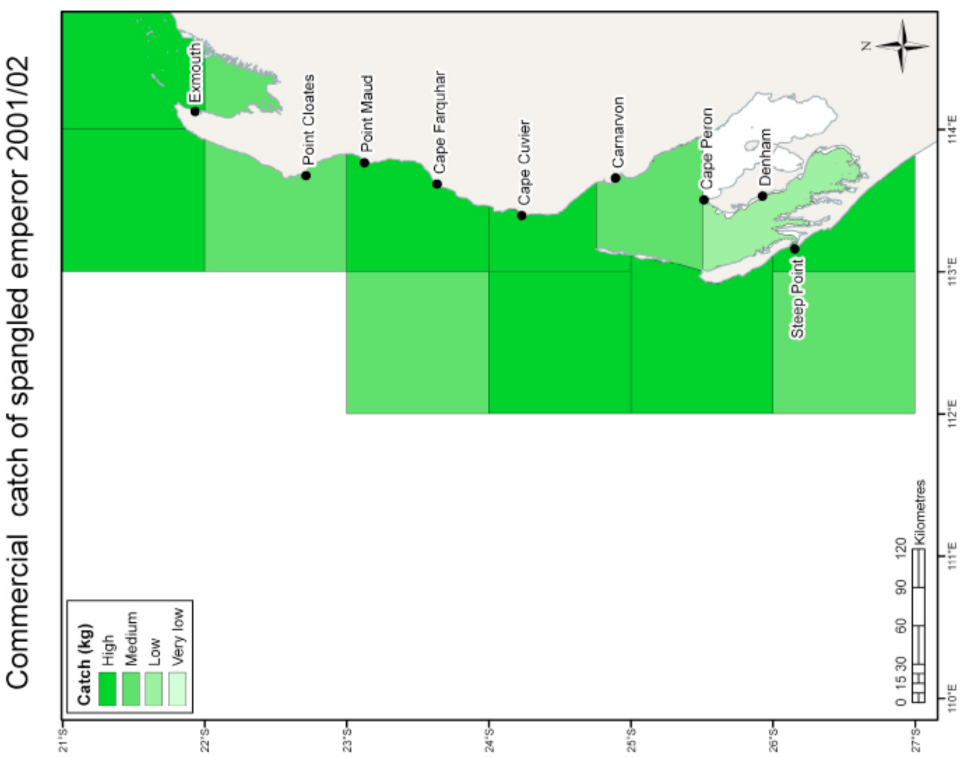




**Figure 6.1.22.** Commercial catch of spangled emperor (all gears) in the Gascoyne Coast Bioregion for 2001/02 (bottom) and 2006/07 (top).

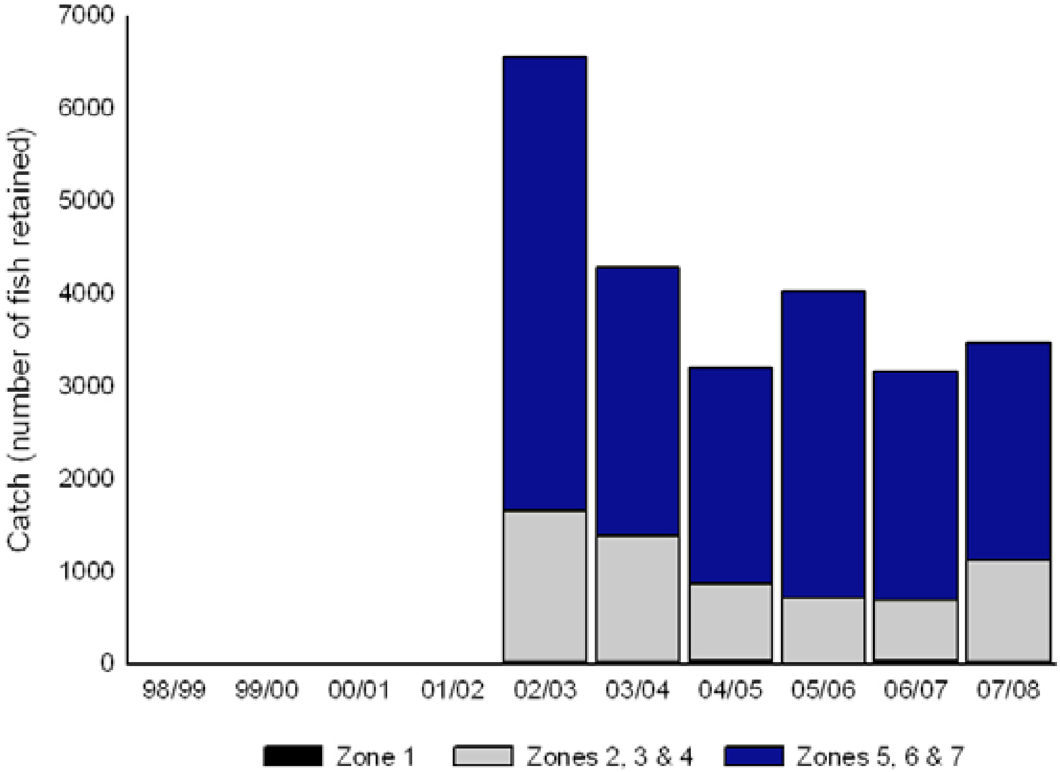



**Figure 6.1.23.** Charter catch of spangled emperor the Gascoyne Coast Bioregion.

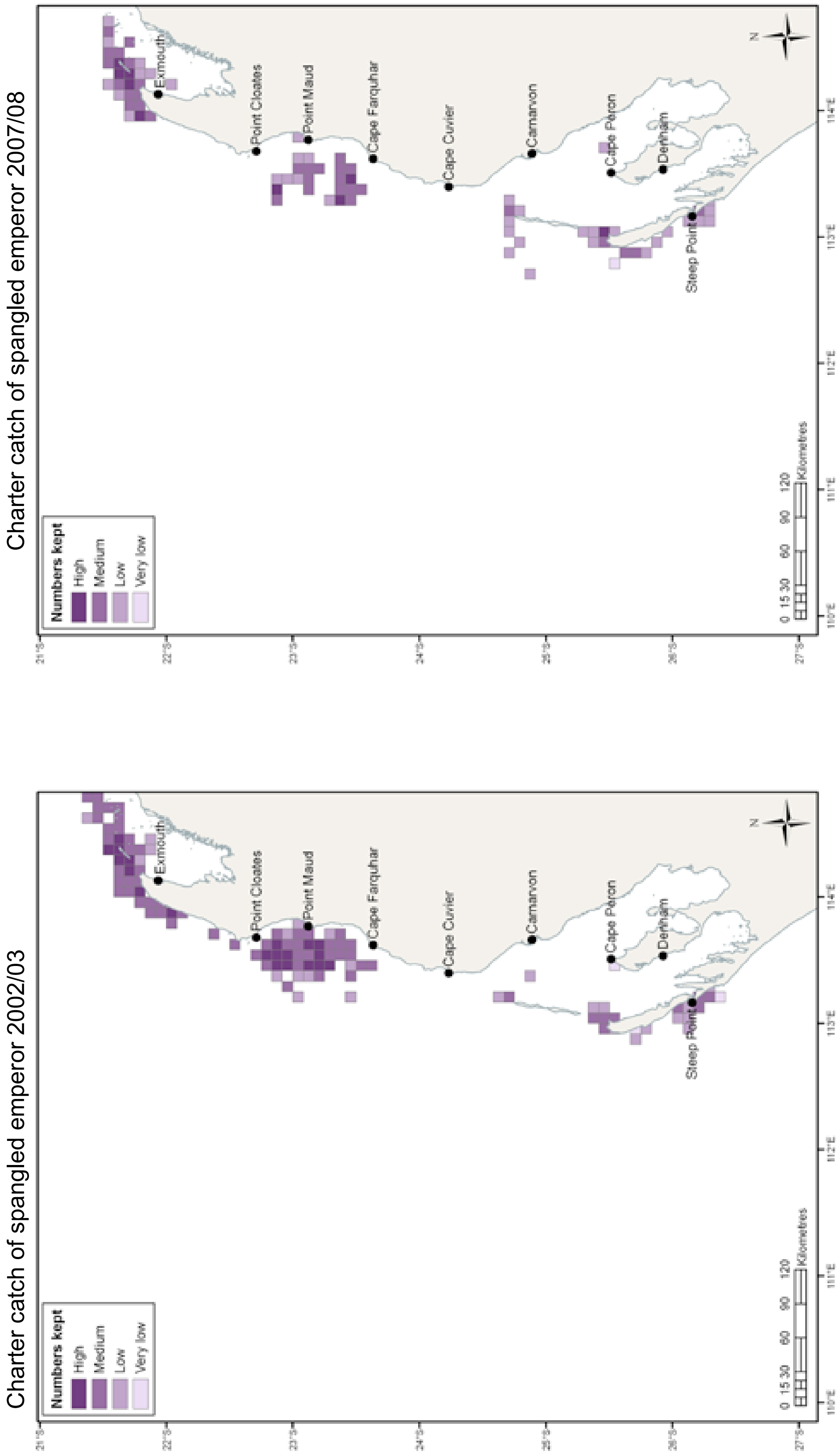



**Figure 6.1.24.** Charter catch of spangled emperor in the Gascoyne Coast Bioregion for 2002/03 (bottom) and 2007/08 (top).

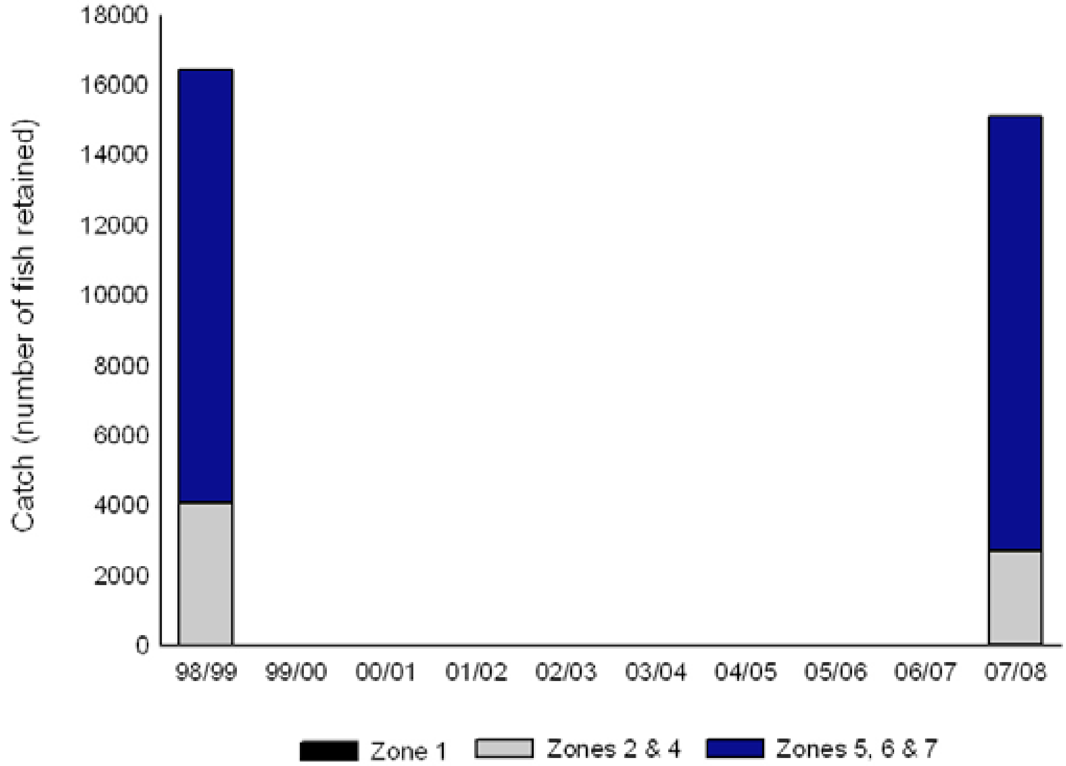
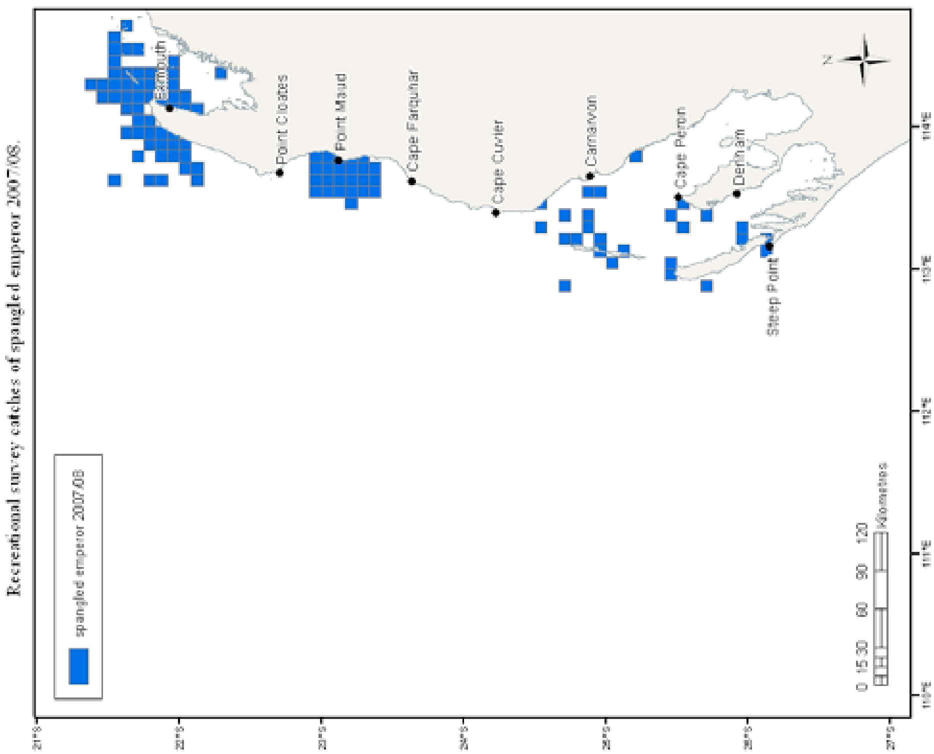



**Figure 6.1.25.** Estimated recreational catch of spangled emperor in the Gascoyne Coast Bioregion.



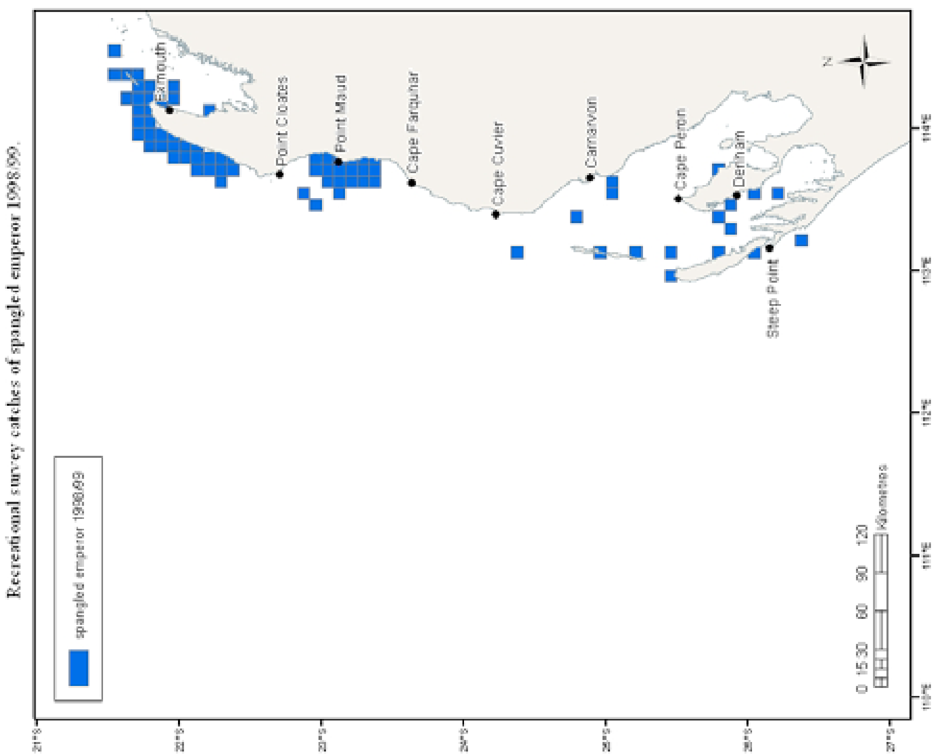




**Figure 6.1.26.** Capture locations of spangled emporer recorded from interviews with recreational boat-based fishers in the Gascoyne Coast Bioregion during 1998/99 (bottom) and 2007/08 surveys (top).

### 6.1.3.4 Goldband snapper catch

The historical commercial catch of goldband snapper in the Gascoyne was relatively low (< 50 t) prior to the 2000/01 season, then increased rapidly to relatively high levels from 2002/03 to 2004/05 before dropping to relatively stable levels from 2005/06 to 2007/08, with most of this catch occurring from Zone 2 (Fig. 6.1.27.). This trend reflects the development of a market for this species and concomitant increase in the targeted fishing of this stock from 1998 to 2003. Catches prior to 1998 were largely incidental as fishers fished in deeper depths (150-250 m) whilst targeting pink snapper. From 1998 to 2003 an increase in demand for catches of this species from the Gascoyne saw an increase in beach price for goldband snapper from $4.50 to $6 per kg by one wholesaler and an increase in the number of vessels recording catches of goldband snapper from 18 to 31. In addition, an exemption for an exploratory commercial fish trawling licence was granted for a single vessel to operate within the 100m to 200m depth contours from south of Point Cloates to Cape Farquhar from 1993/94 to 1996/97, which contributed to observed catches for Zones 2 and 6 over that period (Fig. 6.1.27.). However, most of the catches of goldband snapper made since 2000/01 have been made by handline and dropline methods.

The annual catch of goldband snapper dropped in 2004 following the prohibition of "wetlining" within the SBSF management zone in that year, which limited fishing effort to only those vessels that held sufficient quantities of SBSF catch quota for pink snapper (Fig. 6.1.27.). It is suspected, however, that subsequent reductions in the pink snapper TACC in 2003/04, 2006/7 and 2007/08 resulted in greater effort for goldband snapper and other species in the SBSF (Zones 2 and 3). The number of vessels targeting goldband snapper has gradually reduced since peak catches in 2003, however, as a result of the decreasing size of the SBSF fleet due primarily to increasing fuel prices, reduced profits for vessels with limited pink snapper quota, and apparent optimised economical viability for fewer vessels remaining in the fleet with higher amalgamated units of pink snapper quota per vessel.

Initially the highest annual catches of goldband snapper prior to 2002 were made in the coastal CAES block that includes Point Maud, and catches are still high from this area, although have decreased from 2001/02 to 2006/07 (Fig. 6.1.28.). Since 2002 the goldband snapper catch from that block has also decreased proportionally within the bioregion as the proportion of goldband snapper catch from CAES blocks 24120 and 25120, west and northwest of Shark Bay, has increased. This trend is also evident in comparing spatial distributions of catch between 2001/02 and 2006/07, in addition to a markedly lower catch from the block north of Exmouth Gulf and increasing catches west and south of Steep Point in 2006/07 (Fig. 6.1.28.). Although there is no clear, consistent seasonal pattern in the catches of goldband snapper, there are generally low monthly catches in May and June of each year, reflecting a shift in targeted fishing effort to pink snapper during the peak spawning season. There was also no obvious relationship between goldband snapper catches and the timing of peak spawning for this species.

Catches of goldband snapper by charter fishers are relatively low in comparison, but have increased substantially from 2002/03 to 2007/08, with no catch reported for zone 1 (Fig. 6.1.29.). The majority of these catches are made from fishing grounds to the west of Point Maud, although low levels of catch have also been made to the north of North West Cape (Fig. 6.1.30.). Catches of goldband snapper offshore from Point Maud are conspicuously higher in 2007/08 than in 2002/03 (Fig. 6.1.30.).

The total estimated recreational catch of goldband snapper from the Gascoyne in 2007/08 was mainly from zones 5-7, with a comparatively small amount caught from zones 2-4, and none reported from zone 1. The spatial map of capture block locations show that the small number of goldband snapper caught from zones 2-4 were close to Coral Bay (Point Maud), with catches from zones 5-7 reported offshore from Coral Bay, on the western side of North West Cape (i.e., offshore from Tantabiddi ramp), and near the Muiron Islands (Fig 6.1.32). No recreational catch of goldband snapper was reported in the 1998/99 survey for comparison.

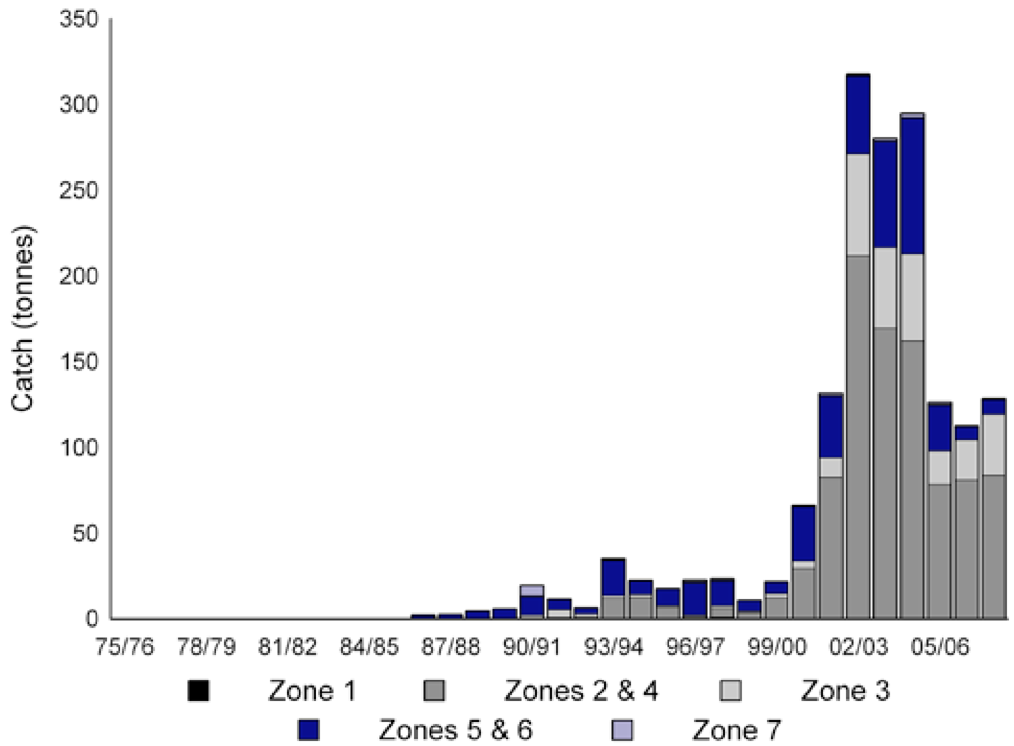



**Figure 6.1.27.** Commercial catch of goldband snapper (all gears) in each zone. Note: apportionments of catch to zones is approximate and based on area for boundary blocks.

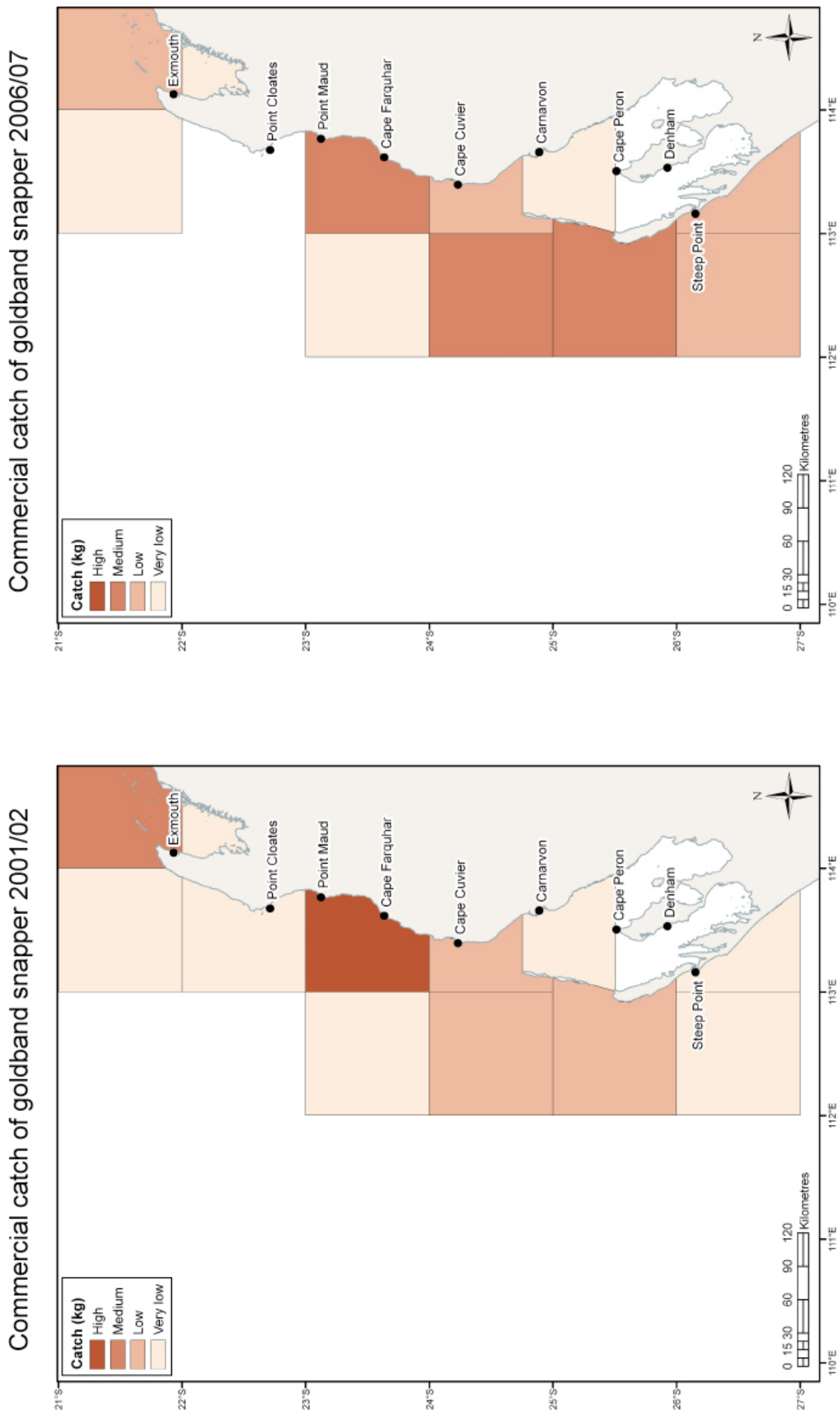



**Figure 6.1.28.** Commercial catch of goldband (all gears) in the Gascoyne Coast Bioregion for 2001/02 (bottom) and 2006/07 (top).

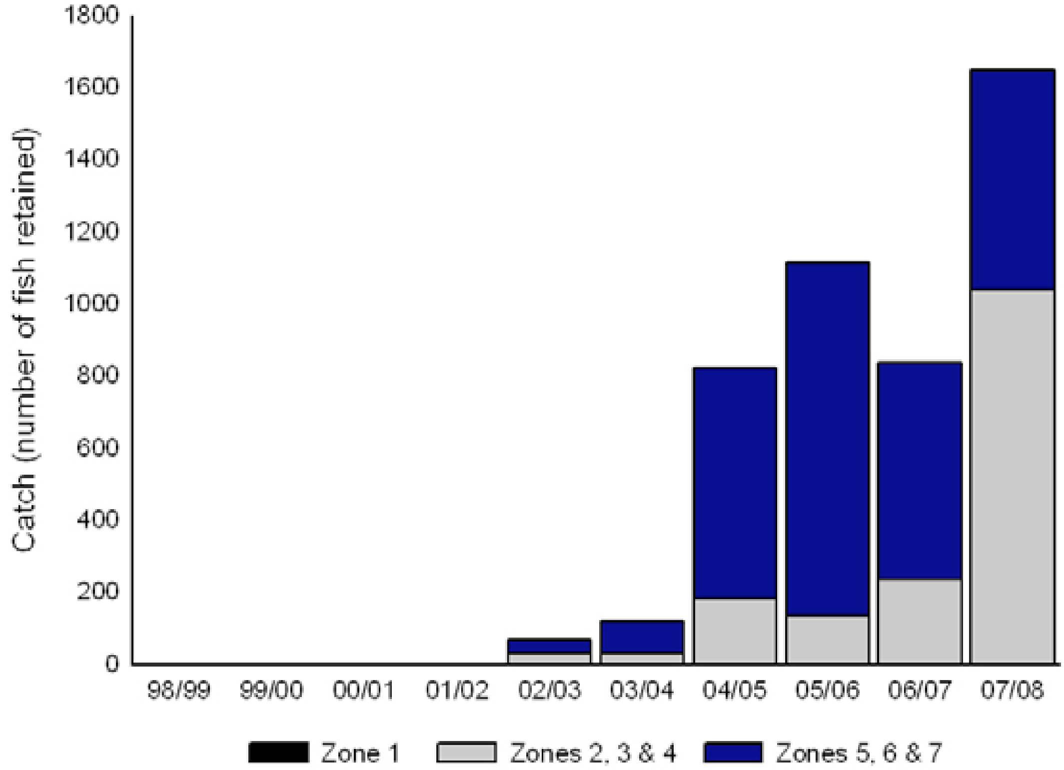
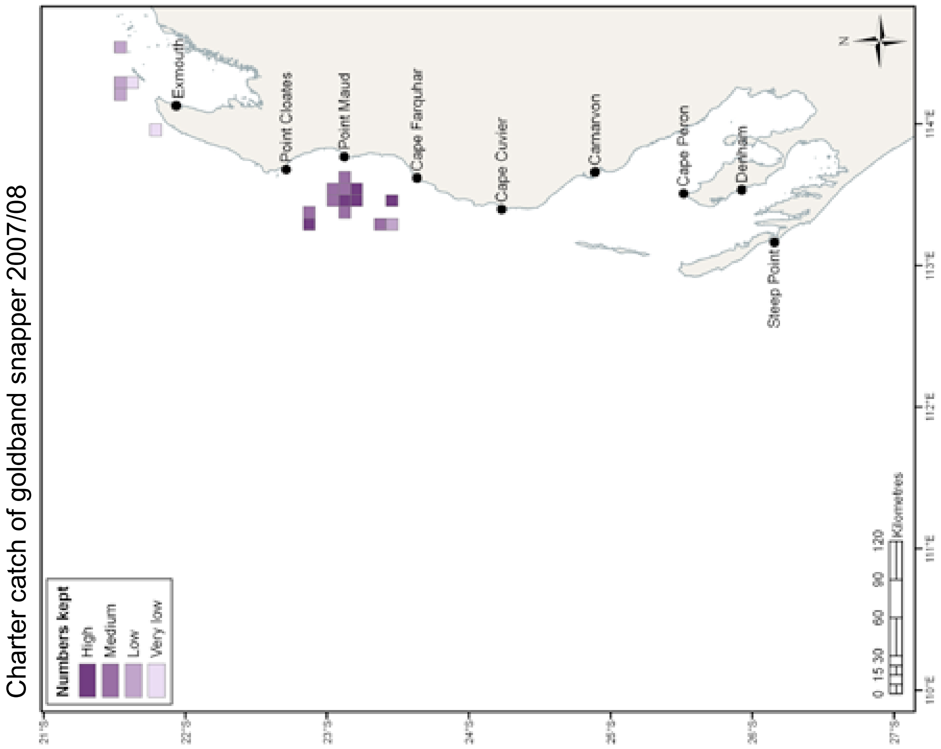



**Figure 6.1.29.** Charter catch of goldband snapper in the Gascoyne Coast Bioregion.



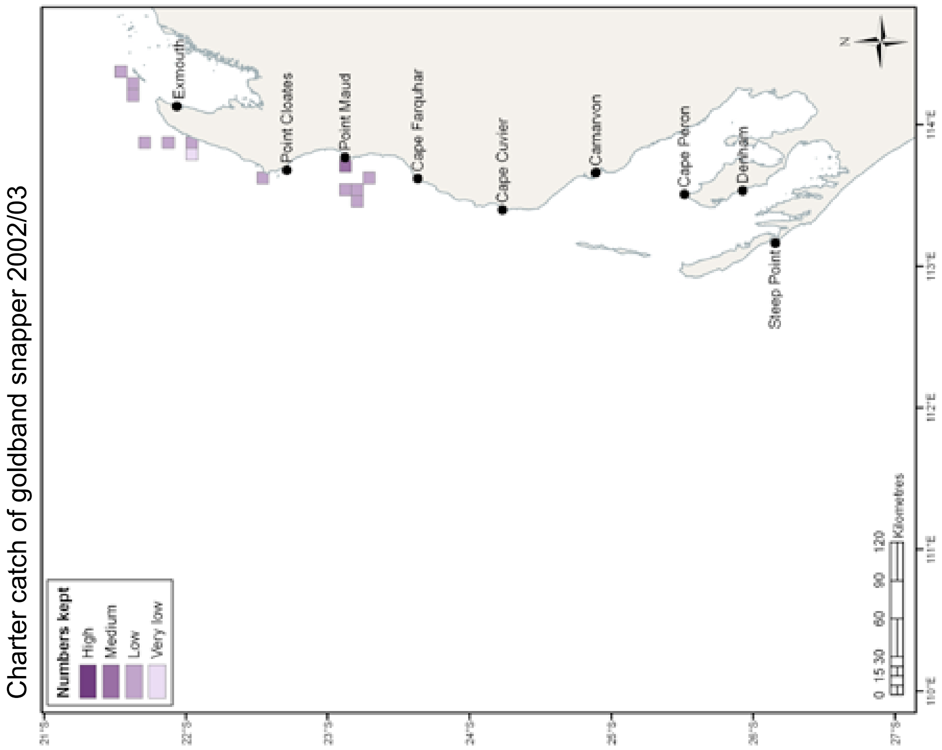




**Figure 6.1.30.** Charter catch of goldband snapper in the Gascoyne Coast Bioregion for 2002/03 (bottom) and 2007/08 (top).

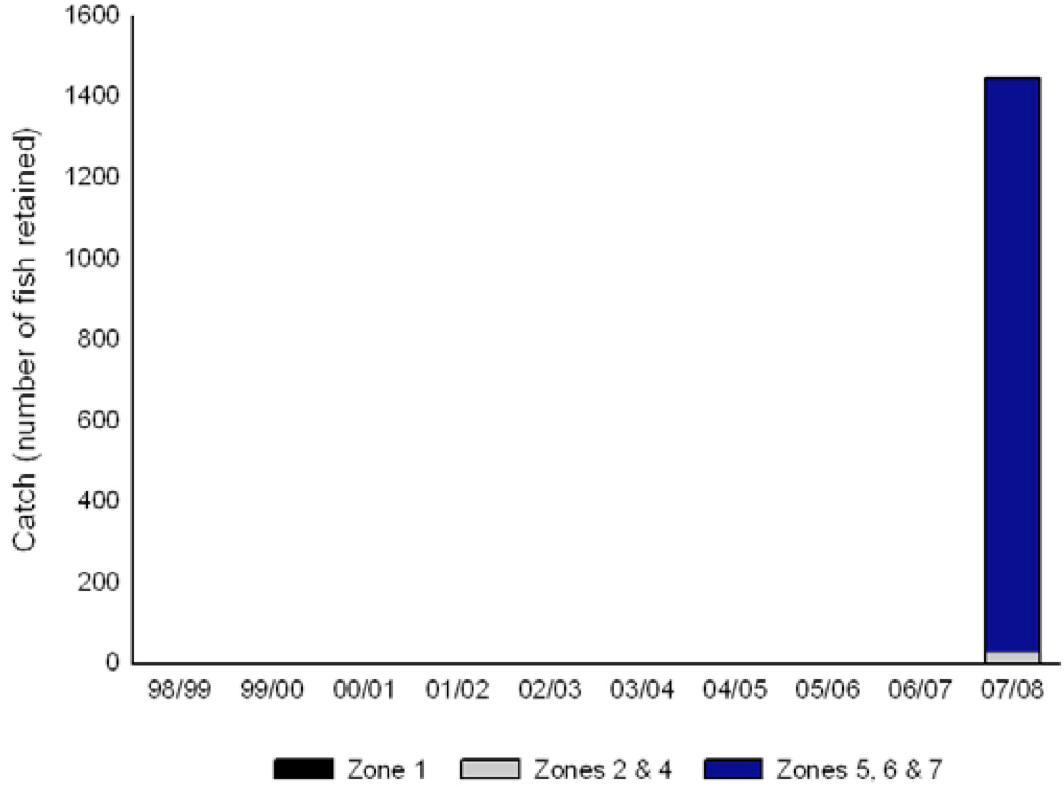



**Figure 6.1.31.** Estimated recreational catch of goldband snapper in the Gascoyne Coast Bioregion.

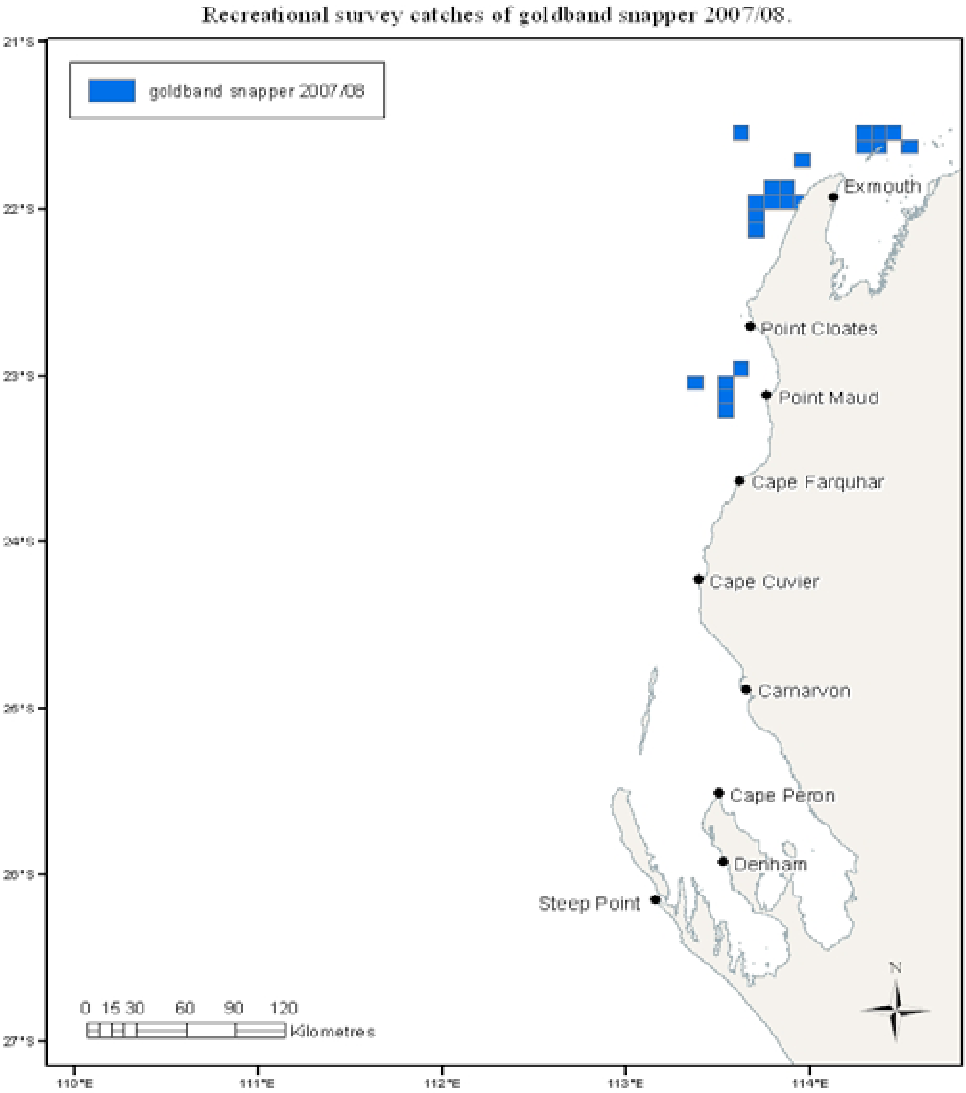



**Figure 6.1.32.** Capture locations of goldband snapper recorded from interviews with recreational boat-based fishers in the Gascoyne Coast Bioregion during 2007/08 surveys. No recreational catches of goldband snapper were reported in the 1998/99 survey.

## 6.2 Commercial catch rate information for key indicator species

### 6.2.1 Introduction

Catch rates, or catch per unit effort (CPUE) data, can provide useful information on stock abundance providing that certain assumptions are met. Nominal or un-standardised catch rates cannot be used as indices of relative abundance if they are not proportional to stock size. Wherever possible, the actual or 'effective' effort should be calculated, taking into account factors such as 'technology-creep' as fishers adopt new technologies or strategies, fishing environmental effects on catchability and observation and process error (Wise *et al.* 2007; Marriott *et al.* 2011b). Additionally, given a catch rate dataset of sufficient size, there are a number of well established statistical approaches that can be applied to produce a time series of standardised catch rates (Kimura 1988; Millischer *et al.* 1999; Marchal *et al.* 2006).

The objective of this section is to present and evaluate CPUE data for the three Gascoyne demersal indicator species in order to investigate long-term trends in relative stock abundance. Catch and effort data from the recreational and charter sectors were only available for two discrete years (1998/99, 2007/08) and for a continuous six-year period (2002/03 – 2007/08), respectively and so were not sufficient to derive CPUE data for that purpose. A much longer time series of commercial catch and effort data were available (i.e. decades) and therefore provided greater scope for developing indices of relative abundance based on CPUE. Because commercial line-fishing in the Gascoyne catches a range of species, a key factor influencing the usefulness of CPUE for this purpose is whether it is possible to accurately calculate the effort targeted towards a species of particular interest. The inadvertent inclusion of effort used in fishing for a non-target species can result in inflated and/or less precise effort terms in the calculation of CPUE and potential indices of abundance.

### 6.2.2 Methods

#### 6.2.2.1 Pink snapper

Although various gears have been used over the recorded history of the SBSF, handline has been the predominant method (Moran *et al*. 2005). Nominal catch rates are highest during winter months, peaking in June-July, when pink snapper aggregate to spawn. Based on these two characteristics of the commercial fishery and in recognition of the need to identify targeted fishing effort, DoFWA has, since the 1990s, estimated a pink snapper CPUE (*kg snapper/boat day*) for SBSF-licensed vessels based on pink snapper catch (*kg snapper*) taken by handline during months of June-July only (*boat days*) (Moran *et al.* 2005). This approach was further refined, to take into account issues arising from the fact that the northern and southern boundaries of the SBSF dissect CAES reporting blocks, differences in skipper experience, with CPUE calculated based on the following criteria (referred to as the 'Moran method', Moran *et al*. 2005):

- SBSF vessels fishing by handline that caught >4 t total ('high-catch vessels') of pink snapper during months June and July only;
- Catches from whole CAES blocks only within proscribed waters of SBSF (dissected blocks at northern and southern margins excluded).

In 2006, as part of an external review of most recent oceanic pink snapper stock assessment at the time, Gilbert* (Department of Fisheries, unpublished data) used a generalised linear modelling (GLM) approach to obtain a standardised CPUE series by fitting a linear model to the logarithm of monthly catch (*C* kg, line fishing only) with year, vessel, month (*M*), days fished (*D*) and number of crew (*G*) as covariates as follows:

$$C_i = \alpha I_i \bullet \; \beta M_i \bullet D_i^{\delta} \bullet G_i^{\varphi}$$

The resultant trend in CPUE using the 'Gilbert GLM' was not significantly different to that obtained using the 'Moran method' (Fig. 6.2.1). Around same time, Thompson (Department of Fisheries, unpublished data) also used a GLM-based approach incorporating the same covariates as Gilbert but also included catches of species (bycatch) other than pink snapper and compared trends in CPUE under six different model scenarios as follows:

- Model 1 - All data
- Model 2 - All data with non significant covariates removed
- Model 3 – Only vessels that fished for >30 days during period April-August each year
- Model 4 - Only vessels that fished for >60 days during period April-August each year
- Model 5 - Only vessels that fished caught >10 t snapper during April-August each year
- Model 3 - Only vessels that fished caught >20 t snapper during April-August each year

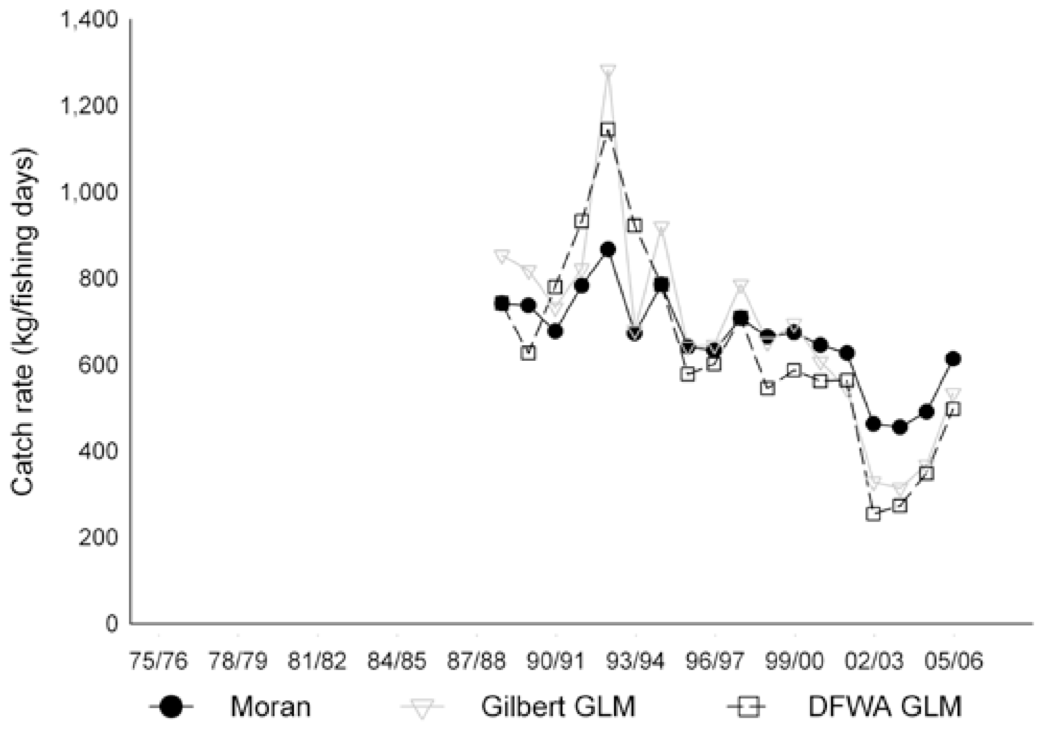



**Figure 6.2.1.** Comparison of the three different measures of pink snapper CPUE 1988/89 to 2005/06.

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* Dr D.Gilbert (NIWA, Wellington, NZ) was contracted to undertake an independent review of the 2006 oceanic pink snapper stock assessment in June 2006. As part of this work, he used GLM to calculate standardised pink snapper catch rates.

Based on ANOVA (type 3 sum of squares), the 'best' CPUE was obtained using catch rates for SBSF vessels that caught >10 t of snapper during period April-August ('DoFWA GLM', Fig. 6.2.1). Following discussions between the Department and SBSF industry leaders in late 2006, at which the merits of the various methods of estimating CPUE based on monthly C&E data were discussed at length, it was agreed that the 'Moran method' would be retained as the standard method of estimating pink snapper catch rate until such time that higher resolution C&E data became available (i.e. daily/trip logbook data). Thus, since 2006, pink snapper catch rates have been calculated using effort measured as 'standard boat days', i.e. days fished by vessels that caught more than 4 t each of pink snapper by handline during June–July each year. CPUE data were incorporated in the age-based integrated model used to assess the oceanic stock of pink snapper (see 6.3.2.1 for details). In addition, CPUE has also been used as an indicator for the SBSF following EPBC Act assessment (in 2003) with the minimum trigger level set at 500 kg snapper/standard boat day.

#### 6.2.2.2 Spangled emperor

Spangled emperor has not been a consistent target species of the Gascoyne commercial fishery (and has not been targeted in recent years), so its CPUE is not likely useful as an index of abundance for this species. A nominal CPUE (total catch divided by the total effort when catches of spangled emperor were made) was therefore presented for each assessment zone (North Gascoyne: Zones 1 to 4 combined, South Gascoyne: Zones 5 to 7 combined) to show the general trend in historical catch rates for the commercial fleet for the most frequently used method of line fishing (handline and dropline). To assist with the interpretation of trends in nominal CPUE, corresponding annual catches are also displayed in these figures.

Historically, the variation in spangled emperor CPUE among vessels is likely to have been significant, since it is known that the level of targeted fishing of spangled emperor among vessels has varied, such as with the relatively recent advent of the targeting of other deeper-water species such as goldband snapper by some vessels (Sections 6.1.3.4, 6.2.3.3). Additionally, the significance of vessel-specific variation on fleet-wide CPUE, attributable to effects such as skipper skill (Hilborn 1985; Squires and Kirkley 1999), vessel horsepower (Jones and Luscombe 1993), product storage technology and capacity (Robins and Sachse 1994), crew size, and other technologies or gears adopted and/or installed on different vessels (Marriott *et al*. 2011b) is well-documented for many other demersal scalefish fisheries. It is therefore possible that changes in the composition of the commercial fleet at different times may have influenced the presented trends in nominal CPUE for spangled emperor. A supplementary analysis of CPUE to account for the influence of vessel using generalised linear models was therefore done and is reported in Appendix 5.

#### 6.2.2.3 Goldband snapper

Goldband snapper is currently a targeted species by commercial demersal scalefish operators, and so was considered a candidate stock for evaluating its CPUE as an index of relative abundance. However, this species has only recently been targeted, so an exploration of factors influencing the effective fishing effort and thus nominal catch rates of goldband snapper over this relatively recent history of exploitation was done.

Six of the top ten skippers who reported annual catches of goldband snapper most frequently ranking in the top ten (kg) for the years 1988 to 2007 were contacted for a phone interview on their historical fishing of goldband snapper in the Bioregion. Specific questions that were asked included:

i. What year did they start commercial line fishing for demersal scalefish?

ii. What year did they start targeting goldband snapper?

iii. What are the five most important factors they think were likely to have influenced their catch rates of goldband snapper over time?

iv. For those factors identified in (iii), can they provide an estimate of the improvement (%) in catch (for same fishing effort) or proportional reduction in fishing effort (%) for the same catch of goldband snapper as a result of each factor?

Estimates of improvements in fishing efficiency provided in response to (iv) were calculated as in Wise *et al.* (2007) and Marriott *et al*. (2011b) for demersal scalefish stocks in the West Coast Bioregion, for the purpose of gauging the approximate magnitude of factors affecting catch rate. This was done to obtain an improved understanding of suspected market influences or technological developments within the fishery on the historic catch rate trend for this species. Informal discussions with fishers and explorations of spatial and/or temporal patterns in catch, CPUE, and number of vessels catching goldband snapper were also undertaken to describe the historical exploitation of that species by the fleet operating in Zone 2 (see also Section 6.1).

Available nominal commercial CPUE data are presented to show annual trends for the South Gascoyne region only. This was done because these data were considered to be representative of the relatively recent history of commercial fishing by fishers in the SBSF targeting goldband snapper and wetliners north of the SBSF management zone but south of the Commercial Exclusion Zone. Nominal CPUE data for goldband snapper in Zones 5 to 7 for this relatively recent harvest period represent commercial fishing in Pilbara waters (a separately managed fishery) and thus represents only part of that separately managed Pilbara stock, which is monitored and managed under separate processes. Therefore, goldband snapper data collected from the North Gascoyne (Zones 5 to 7 combined) were not considered relevant in the context of this section (and of the stock assessments: see Section 6.3) and so were not presented. To account for the influence of method on CPUE, only data for line fishing methods (handline and dropline) were plotted. To assist with the interpretation of trends in nominal CPUE, corresponding annual catches were also displayed in figures. Accordingly, divergent trends in CPUE and catches over time indicated that changes in effort or other factors not directly influencing the catches were affecting the nominal CPUE.

### 6.2.3 Results

#### 6.2.3.1 Pink snapper

Although CAES data for the SBSF were available from 1975 onwards, due to some uncertainties in the licensing information and effort data (E. Lai, pers. comm.), it was only possible to calculate CPUE for pink snapper with confidence from 1989 onwards. Catch rates calculated using the ‘Moran method’, while showing significant inter-annual variation, declined through the 1990s and early 2000s reaching a low of 450 kg/standard boat day in 2003/04. Since that time, the standardised ‘Moran method’ catch rates have increased (Figure 6.2.3). The assessment model indicated a steady increase in catch rates after 2003 that was consistent with the increase in spawning biomass following the significant reduction in TACC in 2004 (see 6.3.3.1).

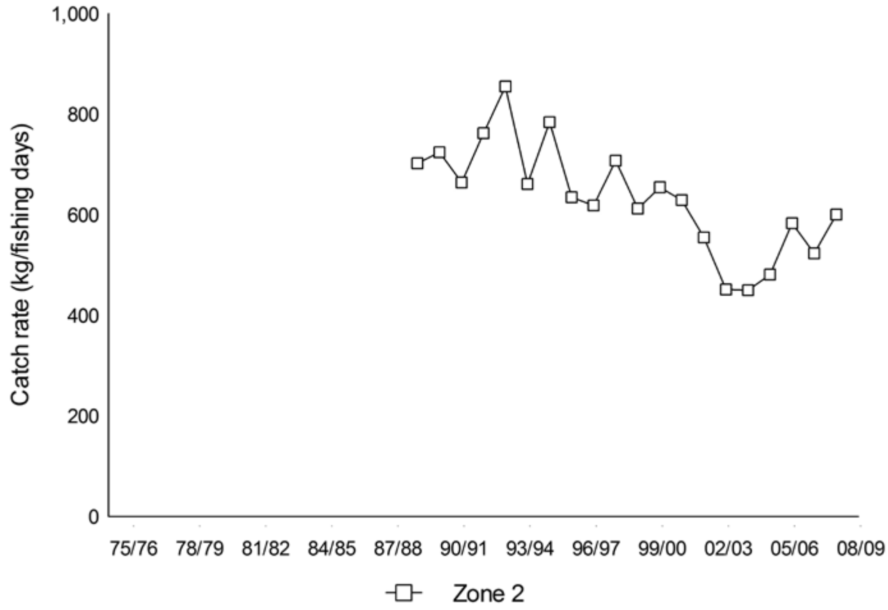



**Figure 6.2.3.** Standardised commercial catch rate for pink snapper 1988/89 to 2006/07 calculated using the 'Moran method'.

### 6.2.3.2 Spangled emperor

The general trend of nominal CPUE in the North Gascoyne was of an overall decline from 1975/76 to 2007/08, punctuated at approximately regular intervals (i.e., every 6-9 years) by 3-4 pulses of elevated CPUE: 1981/82-1983/84, 1988/89-1992/93, 1998/99-2000/01 and, possibly, 2005/06-2007/08 (Fig. 6.2.4). Nominal CPUE generally tracked trends in annual catches except from 1975/76 to 1979/80 when CPUE was decreasing with increasing catches, from 1988/89 to 1991/92, when catches were decreasing and CPUE increased and fluctuated, and from 2003/04 to 2006/07, when CPUE was gradually increasing but catches remained relatively stable before dropping in 2006/07 (Fig. 6.2.4).

The commercial nominal CPUE for spangled emperor in the South Gascoyne declined rapidly from a very high level in 1975/76 to a relatively low level in 1981/82 (Fig. 6.2.4). Whether this early rapid decline in CPUE is due simply to a rapid increase in the number of fishers targeting and catching spangled emperor at that time, a rapid fish-down of a previously unexploited stock, or for some other reason is unknown. Thereafter the trend in spangled emperor CPUE gradually increases to 1991/92 then gradually declined until 2006/07 (Fig. 6.2.4). Nominal CPUE generally tracked the trends in annual catches from 1975/76 to 2007/08 (Fig. 6.2.4). As these are trends in nominal CPUE, they may not necessarily reflect trends in the relative abundance of spangled emperor in either region, because they could also reflect the combined influences of the other aforementioned factors on catch rates (Wise *et al.* 2007; Marriott *et al.* 2011b), including structural adjustments with the fishery (see Section 6.1).

A supplementary analysis of spangled emperor CPUE demonstrated that vessel-specific CPUE was significant (Appendix 5). Also, the fleet composition had changed frequently over time. Accordingly, it is probable that a change in fleet composition could have at least partly explained some of the observed historical changes in nominal CPUE. That there was a large reduction in effort in the North Gascoyne from 1991/92 onwards, which was concomitant with the commencement of the Pilbara Trap fishery, suggests that the rapid decline in nominal CPUE from 1991/92 to 1996/97 was likely attributed, at least in part, to a change in fleet composition and reduction in fishing activity during that period, although it was not possible to test this given the relative paucity and coarseness of available data (see Appendix 5). It is likely that regulations introduced in the North Gascoyne resulting in restricted commercial fishing in waters inhabited by spangled emperor, including the establishment of the Ningaloo Marine Park in 1989, the implementation of sanctuary zones within it in 1991, and the establishment of the OCS in 1995 (i.e., to enforce prohibition of state-licensed commercial fishing within the Commercial Fishing Exclusion Zone; Fig. 1.1) contributed towards observed declines in catches and CPUE during that period.

However it is also possible that a declining CPUE could reflect a declining abundance of spangled emperor following higher historic levels of commercial exploitation in the vicinity of North West Cape and Ningaloo, or other factors not explored. Moran *et al.* (1993) interpreted a declining commercial trap fishing CPUE of large emperors (including spangled emperor) from those areas since 1989/90 as reflecting serious depletions from intensive commercial trap fishing from the mid to late 1980s. Although there is much uncertainty in the interpretation of CPUE trends due to the many factors unquantified and unaccounted for in such analysis (see Appendix 5), this possibility of high historical depletions of spangled emperor in the North Gascoyne should be considered in context of assessment results presented in Section 6.3.

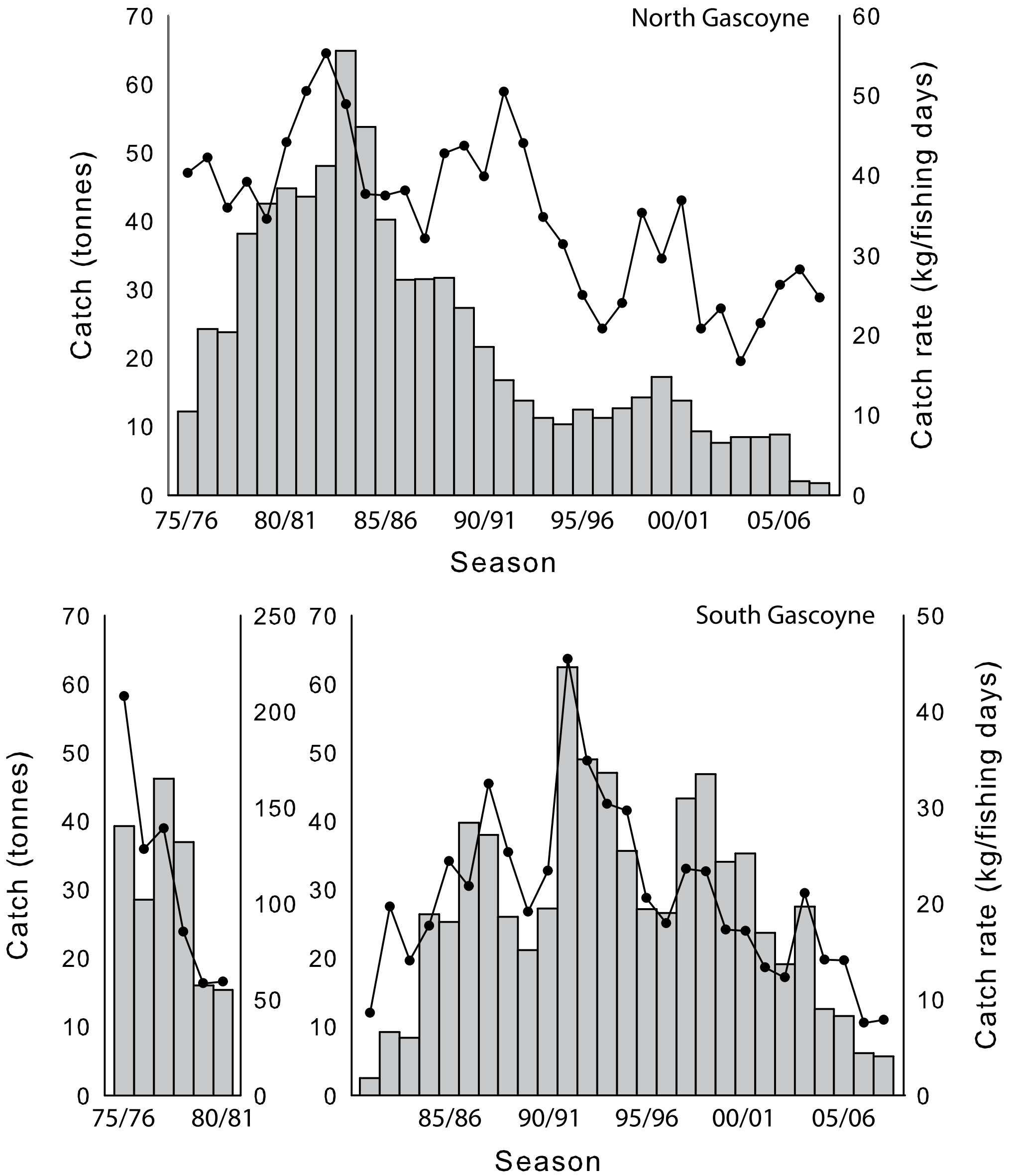



**Figure 6.2.4.** Nominal commercial catch rate for spangled emperor, with annual commercial catches included for comparison. South Gascoyne = Zones 1 to 4 combined; North Gascoyne = Zones 5 to 7 combined. Data presented for line fishing methods (handline and dropline) only.

### 6.2.3.3 Goldband snapper

The historical trend in nominal CPUE of goldband snapper for the South Gascoyne (Fig. 6.2.5) follows the trend of historical catches from that region, except for the relatively rapid increase in nominal CPUE from 2005/06 to 2007/08, compared to a more gradual increase in catch. The increase in nominal CPUE and catches from 1998/99 to 2003/04 likely reflects the development of the market for goldband snapper captured from the Gascoyne Coast Bioregion as described in Section 6.1.3.4 and improvements in targeted fishing for this species, and not an increase in relative stock abundance over this period. Several skippers who currently target goldband snapper explained the relatively rapid increase in nominal CPUE from 2005/06 to 2007/08 arising from the recent reduction in the number of vessels in the SBSF that target this species (as explained in Section 6.1) and that those who remained in the fishery were highly efficient at catching them. Thus this recent increase in CPUE reflects a shift in fleet composition to those few operators who were highly efficient at targeting and catching this species, rather than an increase in relative stock abundance.

Improved depth sounders, weather and the use of tuna circle hooks were equally the most frequently identified factors for influencing historical catch rates of goldband snapper reported by the interviewed fishers. Responses of the interviewed skippers were consistent with the aforementioned inferences relating historical fleet-wide trends in catches and CPUE to a shifted targeting of fishing effort towards this species. The interviewed skippers stated that they started targeted fishing for goldband snapper in the Gascoyne from 1994 to 2001 (i.e., where this year did not coincide with the year that respondents had stated that they had started fishing for demersal scalefish). This period bracketed the inferred year that a fleet-wide shift to targeted fishing of goldband snapper commenced (i.e., 1998/99), based on the historical trends of catches and CPUE. Half of the interviewed skippers had adopted better depth sounders since they had started targeted fishing for goldband snapper to result in an estimated 20% median improvement in the fishing efficiency for goldband snapper catches. These fishers had adopted the improved depth sounders from 2003 to 2007.

Therefore, historical catch rate data from the SBSF were found to be uninformative for use as an index of relative abundance of goldband snapper and it was not possible to robustly estimate relative stock biomass for this species from these historical data. There is promise for developing a reliable index of abundance for this stock from CPUE data in future, however, since the market for goldband snapper from the Gascoyne Bioregion is now fully established and higher-resolution commercial daily/trip logbook data collection is now in progress (since early 2008).

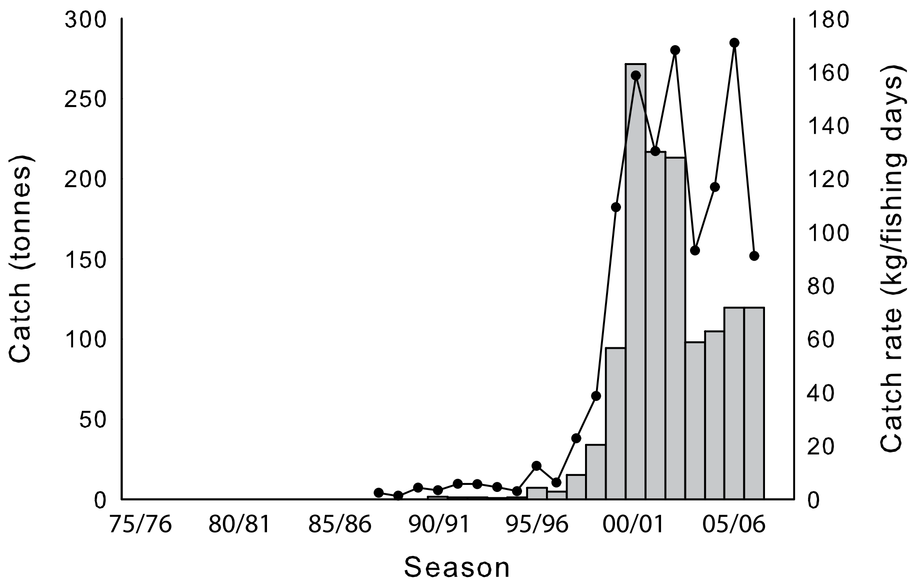



**Figure 6.2.5.** Nominal commercial catch rate for goldband snapper from the South Gascoyne (Zones 1 to 4 combined), with annual commercial catches included for comparison. Data presented for line fishing methods (handline and dropline) only.

### 6.2.4 Discussion

Evaluation of commercial CPUE data and historical fishing practices showed that a useful index of relative abundance can be derived for pink snapper (oceanic stock) but not for goldband snapper or spangled emperor at this stage. The trend in historical CPUE for goldband snapper was driven by an increased level of targeting and improved efficiency for catching this species and the available time series of CPUE since this species was fully targeted is limited. For spangled emperor, it was not possible to disentangle the likely effect of observed changes in fleet composition in the North Gascoyne from underlying patterns in relative biomass on a declining CPUE. In the South Gascoyne, it is possible that a declining CPUE may have reflected a declining relative biomass of spangled emperor from at least 1991/92 to 2000/01, because a supplementary analysis corroborated the observed trend in nominal CPUE when the effect of vessel was accounted for. It is possible, however that other unexplored effects might have influenced this CPUE trend, such as the shift in targeting to more highly valued deeper-water species such as goldband and ruby snapper from 1994 to 2001. This might have resulted in reduced targeted fishing for spangled emperor (when not targeting pink snapper) within each 60 x 60 nm block for each month and therefore a reduced vessel-adjusted or nominal CPUE over time. This has significant implications for stock assessments of goldband snapper and spangled emperor, because without a long-term time series of relative biomass, there is greater uncertainty in estimates of stock status and reduced scope for the application of integrated age-structured stock assessment models (Doubleday 1976; Deriso *et al*. 1985; Megrey 1989).

New logbooks with higher spatial (10 x 10 nm reporting blocks) and temporal (hours) resolution, were recently implemented in the SBSF (and in the Gascoyne Demersal Scalefish Fishery, which commenced on 1 November 2010), and are likely to provide scope for generating improved standardised indices of relative abundance for pink snapper and goldband snapper in the future.

There is also scope for new data on recreational catches and effort and data from charter fishing logbooks to generate standardised indices of abundance for spangled emperor in the Gascoyne, and in particular in the north Gascoyne (Zones 5 to 7 combined), where adequate data from a commercial sector is lacking. Hourston and Johnson (2009) demonstrated the potential usefulness of trends in charter fishing catches, effort and CPUE for monitoring spangled emperor, goldband snapper and pink snapper in the Commonwealth waters of the Ningaloo Marine Park. For instance, they found that, with a declining number of vessels, effort, catch and overall change in catch composition, a reduction in CPUE for spangled emperor from 2002 to 2008 (Hourston and Johnson 2009). However, they could not determine whether this was due to changing fish biomass or fishing behaviour. The Department has since (from January 2011) commenced a new recreational fishing survey, which is planned to be run every two years to collect catch and effort data at a state-wide and Bioregional level. With regular data on recreational and charter catch and effort collected for spangled emperor and goldband snapper from the Gascoyne it may be possible to move to higher-level stock assessments for these stocks in future.

## 6.3 Assessments

### 6.3.1 Introduction

The scope and quality of fishery and biological data available for the stock assessments varied considerably among the three Gascoyne demersal indicator species. As a consequence, different assessment approaches were used for the respective stocks. The historical data that were available for pink snapper allowed the application of integrated age structured models for both the oceanic and inner gulfs stocks (Stephenson and Jackson 2005; Moran *et al.* 2005); assessments were not undertaken as part of the Gascoyne IFM *per se* but had been undertaken recently (in 2009 and 2008, respectively) to meet pre-existing fishery management commitments. In contrast, historical data for spangled emperor and goldband snapper were considered poor for indicating trends in relative abundance (Section 6.2) and thus assessments for these stocks necessitated a lower level approach that made use of the 'weight-of-evidence' framework developed by Wise *et al.* (2007).

### 6.3.2 Methods

#### 6.3.2.1 Integrated age-structured assessments: Pink snapper

##### 6.3.2.1.1 Background

There are fundamental differences between the fisheries that target the oceanic pink snapper stock (mostly commercial) and inner gulf pink snapper stocks (mostly recreational). As a consequence, the sources of data available for the respective assessments differed as follows:

***Oceanic stock***

The oceanic stock is nowadays principally fished by commercial vessels operating within the Shark Bay Snapper Managed Fishery (SBSF, see 6.1). An extensive time series of CAES catch (1952-present) and effort data (1989-present) plus a considerable amount of biological information were available (Moran *et al.* 2005; Wakefield 2006). Since 2004, the Department of Fisheries have been sampling SBSF catches on a monthly-basis to provide catch-at-age data to monitor recovery of the stock following major quota cuts in 2004 and 2007 (Jackson *et al.* 2010a). Prior to 2002/03, the only quantitative assessment for the fishery was an MSY-type assessment that was undertaken in 1986 (Moran *et al.* 2005). In 2002/03, an integrated age-based stock assessment model was developed to assess the status of the oceanic stock (Moran *et al*. 2005). The model was independently reviewed in 2006 (by Dr D Gilbert, NIWA, Wellington, New Zealand). The model was subsequently modified (in 2007) to take into account some of the reviewers comments; the model is now updated every 3-years to provide research advice on stock status The most recent assessment, the details of which are reported here, was undertaken in 2009 and included data up to and including the 2007/08 commercial quota season.

***Inner gulf stocks***

The inner gulf stocks have almost been entirely fished by recreational vessels since ca. 1995/96. Prior to a comprehensive research program that commenced in 1997, limited information on the level of recreational catches or the biology of inner gulf stocks was available (Stephenson and Jackson 2005; Jackson 2007). Significant commercial fishing is known to have taken place in the inner gulfs from around the 1950s (Bowen 1961), however, due to the size/design of the CAES reporting blocks, it is not possible to distinguish between catches for the separate stocks with confidence prior to 1992.

Since 1998, surveys to estimate spawning biomass using the daily egg production method (DEPM, Jackson and Cheng 2001; Jackson *et al.* in press) and recreational fishing surveys to estimate catch and fishing effort using the bus-route method (Sumner *et al.* 2002), have provided the basis for the assessment of the status of inner gulf snapper stocks. In 2002, integrated age-structured models were developed to assess the status of each of the three inner gulf snapper stocks (Stephenson and Jackson 2005). These models are updated every 3-years; the most recent assessments that are reported here were undertaken in 2008 and included data up to and including 2007.

#### 6.3.2.1.2 Description of models

A separate age-structured model was developed for each stock based on the substantial body of stock structure evidence (Jackson 2007) that indicates that each pink snapper stock is reproductively isolated and self-recruiting with no significant mixing after recruitment.

The virgin recruitment was estimated and the virgin biomass calculated with the numbers at age reduced by natural mortality. The initial biomass (at the beginning of the respective time series of catch data, i.e. 1952 for oceanic stock and 1983 for the inner gulf stocks) were calculated assuming a constant harvest rate, $H$ , set at 0.05, prior to 1952 (oceanic stock) and 1983 (inner gulf stocks), respectively (Table 6.3.1). Subsequently, numbers in each age class and each year were reduced by natural mortality and fishing mortality. Annual recruitment each year (i.e. number of 0+ fish for inner gulf stocks, number of 1+ fish for oceanic stock) was calculated using a Beverton and Holt stock-recruitment relationship (SRR) with recruitment variability accounted for using recruitment deviation parameter, $\varepsilon_y$ . The first year of recruitment deviations was determined by the time series of age-composition data available, i.e. 1997-2007 for the inner gulf stocks, 1991/92-2007/08 for the oceanic stock (Table 6.3.1).

The female spawning biomass of the oceanic stock, both at the virgin (unexploited) level and at the beginning of the time series of catch data (1952) were estimated using the age composition, sexual maturity of females at age, and weight at age (assumed constant over time) (Tables 6.3.3, 6.3.4, 6.3.5). For the three inner gulf stocks, the total spawning biomass (weight of males and females combined) was estimated at the virgin level and at the beginning of time series of catch data (1983). Independent estimates of total spawning biomass based on the DEPM were available for the three inner gulf stocks for the period 1997-2007 (Jackson and Cheng 2001; Jackson 2007) (Table 6.3.6). The method estimates spawning biomass from the ratio of daily egg production, over the spawning area, and the weight-specific daily fecundity (Lasker 1985). For the oceanic stock, in the absence of independent estimates of stock biomass, catch rates, estimated using the 'Moran method' (see 6.2 for details) were used as an index of relative abundance.

Annual catches taken by commercial (since 1952) and charter vessels (since 2001 only) were obtained from statutory monthly returns reported via CAES (Table 6.3.2). Estimates of recreational catches were obtained from data collected during recreational fishing surveys in 1998/99 and 2007/08 for the oceanic stock and each year 1998/99 -2007/08 for the inner gulf stocks (Table 6.3.2).

Age composition data were obtained from sectioned otoliths sampled from commercial catches (oceanic stock) and fishery-independent surveys (inner gulf stocks) (Table 6.3.3). The selectivity at age, $v_a$ , was taken as the proportion of fish in each age class that are legal size and was assumed to be equivalent for females and males (Table 6.3.7). The different legal lengths that apply in oceanic waters and inner gulfs were accounted for in the respective models. For oceanic pink snapper, this was the proportion at age greater than 41 cm (TL). In the inner gulfs, prior to 2001, this was the proportion at age greater than 45 cm (TL) and from 2001 onwards, the proportion between 50 and 70 cm. It was assumed that all fish above the minimum legal length in each case were fully selected.

The number of pink snapper in the fishery at the start of year $y$ is determined by;

$$N^{s}_{a+1,y+1} = \begin{cases} R_y & \text{if } a = k \\ \left(N^{s}_{a,y}\, e^{-0.5M} - C_{a,y}\right) e^{-0.5M} & \text{if } k < a \le A \\ \left(N^{s}_{A,y}\, e^{-0.5M} - C_{A,y} + N^{s}_{A-1,y}\, e^{-0.5M} - C_{A-1,y}\right) e^{-0.5M} & \text{if } k = A \end{cases}$$

The proportion of females mature at age *a* is $P_a = \left(1 + e^{-\ln(19)\left(\frac{a - a_{0.5}}{a_{0.95} - a_{0.5}}\right)}\right)^{-1}$

The estimated biomass of spawning females (tonnes), $S_y$, and the estimated mature biomass (males and females) at the end of each year is estimated by

$$S_y = \sum_{a=k}^{A} N^{f}_{a,y} p_a W^{f}_a \quad \text{and} \quad \hat{D}_y = \sum_{s=m,f} \sum_{a=0}^{A} N^{s}_{a,y}\, P_a\, W_a$$

The number of pink snapper (millions), at unfished equilibrium, the initial state, is

$$N^{s}_{a+1,init} = \begin{cases} (1-\rho) R_{init} e^{-aM} & \text{if } s = \text{male} \quad \text{and } k \le a < A \\ \rho R_{init} e^{-aM} & \text{if } s = \text{female} \quad \text{and } k \le a < A \end{cases}$$

The number of *k*-year-old recruits in each year is

$$N^{s=\text{female}}_{k,y+1} = \frac{S_y}{\alpha + \beta S_y}$$

The stock-recruitment parameters $\alpha$ and $\beta$ were calculated from the proportion of $R_{init}$ that recruits when $S_y$ is 20% of the virgin level (Hilborn and Walters 1992).

where

$$\alpha = \frac{S_1}{R_{init}} \left(1 - \frac{h - 0.2}{0.8h}\right) \quad \text{and} \quad \beta = \left(\frac{h - 0.2}{0.8 h R_{init}}\right)$$

The number of pink snapper (millions), at the start of year *I*, the initial year of the dataset is

$$N^{s}_{a+1,I} = \begin{cases} (1-\rho) R_I\ (1-H) e^{-aM} & \text{if } s = \text{male} \quad \text{and } k < a < A \\ \rho R_I\ (1-H) e^{-aM} & \text{if } s = \text{male} \quad \text{and } k < a < A \end{cases}$$

The number of recruits at the beginning of subsequent years is given by,

$$N_{0,y+1} = \begin{cases} R_y & y = K \\ R_y\, e^{\varepsilon_y} & I_2 < y \le 2008 \\ R_y\, e^{N(0,\sigma_y{}^2)} & y > 2008 \end{cases}$$

where $K$ represents the first year of recruitment deviations.

The exploitation rate was estimated by,

$$F_y = \frac{C_y}{\sum_{s=m,f} \sum_{a=0}^{A} N_{a,y}^{s} v_a W_a^{s}}$$

The number of fish caught is

$$C_{a,y} = N_{a,y}^{s} e^{0.5M} F_y v_a W_a^{s}$$

The vulnerable biomass (tonnes), $B_y$, at the mid-point of the year is

$$B_y = \sum_{s=m,f} \sum_{a=2}^{A} N_{a,y}^{s} v_a W_a^{s}$$

and the estimated catch rate in each year $\hat{U}_y$ is given by

$$q\,B_y$$

where q is the catchability

The logarithm of the likelihood function associated with catch rates (oceanic stock only) is

$$\lambda_1 = \sum_{y=1992}^{2008} \frac{(\ln(\hat{U}_y) - \ln(U_y))^2}{2\sigma_U^2} + 0.5\ln(2\pi\sigma_U^2)$$

The model estimated proportion at age is

$$\hat{p}_{a,y} = \frac{\sum_{s} N_{a,y}^{s}}{\sum \sum^{A} N_{a,y}^{s}}$$

The logarithm of the likelihood function associated with age samples is

$$\lambda_2 = \sum_{\substack{y \\ \text{sample exists}}} K_y \sum_{a=0}^{A} p_{a,y} \log(\hat{p}_{a,y})$$

The logarithm of the likelihood function associated with the independent DEPM estimates of spawning biomass observations (inner gulf stocks only) is given by

$$\lambda_1 = \frac{\sum\limits_{\substack{y \\ D_y \text{ exists}}} \left(D_y - \hat{D}_y\right)^2}{2\left(CV_y D_y\right)^2} + 0.5\ln\left(2\pi\left(CV_y D_y\right)^2\right)$$

The annual recruitment deviations in each area were assumed to have a log-normal distribution with $\sigma_r = 0.5$. The contribution to the logarithm of the likelihood function is

$$\lambda_3 = \frac{1}{2\sigma_r^2}\sum_y \varepsilon_y^2$$

The natural mortality, $M$, was assumed to have a log-normal prior with $cv$ = 0.2 and mean $\widetilde{M} = 0.12$. The contribution to the logarithm of the likelihood function is

$$\lambda_4 = -\frac{(M - \widetilde{M})^2}{2\sigma_M{}^2} \quad \text{where} \quad \sigma_M = M \cdot CV$$

The total log-likelihood, $\lambda = -\lambda_1 - \lambda_2 - \lambda_3 - \lambda_4$ was minimised using AD model builder to estimate the parameters $R_y$, $V_a$, and $\varepsilon_y$.

Where,

| | |
|---|---|
| $R_{init}$ | = estimated number of 0+ at unexploited equilibrium |
| $N^s_{a,init}$ | = number of fish of sex, $s$, and age, $a$, in the initial year |
| $N^s_{a,y+1}$ | = number of fish of sex, $s$, age, $a$, in year, $y$ |
| $M$ | = annual rate of natural mortality |
| $F_y$ | = exploitation rate in year $y$ |
| $V_a$ | = proportion of vulnerable snapper of age $a$ |
| $C_y$ | = weight of annual catch |
| $C_{a,y}$ | = catch in numbers |
| $W$ | = weight |
| $A$ | = maximum age |
| $\alpha$, $\beta$ | = parameters of the stock recruitment relationship |
| $h$ | = steepness of the stock recruitment relationship |
| $P_a$ | = proportion of snapper mature at age $a$ |
| $a_{0.5}$, $a_{0.95}$ | = ages when 50% and 95% of fish are mature |
| $\rho$ | = proportion of females in the population |
| $R_y$ | = recruitment in the fishery from the stock recruitment relationship |

$\varepsilon_y$ = annual recruitment deviation for year $y$

$\hat{p}_{a,y}$ = model estimated proportion of fish at age $a$, in year $y$

$K_y$ = number of fish in the age composition sample

$D_y$ = empirical estimate of biomass of sexually mature fish (males and females)

$\hat{D}_y$ = model estimated biomass of sexually mature fish (males and females)

$S_y$ = spawning biomass, females only

**Table 6.3.1.** Summary of information used in integrated assessments of oceanic and inner gulf pink snapper stocks in Gascoyne Coast Bioregion.

| Stock | Data | Year/s | Source / Section |
|---|---|---|---|
| *Oceanic* | vB growth | | Wakefield (2006), 5.2 |
| | Maturity | | Wakefield (2006), 5.2 |
| | Length:weight relationship | | Wakefield (2006), 5.2 |
| | Age structure of catch | 1992,1996,1999,2001, each year 2003-2008 | Fishery-dependent sampling, otolith interpretation |
| | Commercial catches | 1952-2008 | Statutory monthly returns (CAES) |
| | Recreational catches | 1998/99, 2007/08 | Gascoyne Recreational Fishing surveys |
| | Charter catches | each year, 2001-present | Statutory monthly returns |
| | Discard rates | 2003-2009 | At sea monitoring |
| *Inner Gulfs* | vB growth | | Jackson *et al.* (2010b), 5.2 |
| | Maturity | | Jackson *et al*. (2010b), 5.2 |
| | Length:weight relationship | | Jackson (2007), 5.2 |
| | Age structure | 1997-2007 | Fishery-independent sampling |
| | Commercial catches | 1992-2007 | Statutory monthly returns (CAES) |
| | Recreational catches | 1983, 1996, 1998/99 – 2007/08 | Recreational fishing surveys (boat ramps) |
| | Charter catches | each year, 2001-present | Statutory monthly returns |
| | Estimates of spawning biomass | 1997-2007 | DEPM surveys (Jackson *et al*. 2012) |

**Table 6.3.2.** Recreational and commercial catches (tonnes) of pink snapper for the inner gulf stocks (Denham Sound, Freycinet Estuary, Eastern Gulf) and total catch (commercial, recreational and charter combined) for the oceanic stock. Recreational catches in inner gulfs 1983-2003 are unknown and have been 'assumed' at three levels (i.e. high, medium and low) based on anecdotal information from fishers.

| Oceanic | | | Denham Sound | | | | Freycinet Estuary | | | | Eastern Gulf | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Catch | Catch rate | Com | Rec | | | Com | Rec | | | Com | Rec | | |
| | | | | Low | Med | High | | Low | Med | High | | Low | Med | High |
| 1952 | 216 | | | | | | | | | | | | | |
| 1953 | 314 | | | | | | | | | | | | | |
| 1954 | 353 | | | | | | | | | | | | | |
| 1955 | 491 | | | | | | | | | | | | | |
| 1956 | 465 | | | | | | | | | | | | | |
| 1957 | 282 | | | | | | | | | | | | | |
| 1958 | 304 | | | | | | | | | | | | | |
| 1959 | 741 | | | | | | | | | | | | | |
| 1960 | 611 | | | | | | | | | | | | | |
| 1961 | 642 | | | | | | | | | | | | | |
| 1962 | 507 | | | | | | | | | | | | | |
| 1963 | 561 | | | | | | | | | | | | | |
| 1964 | 359 | | | | | | | | | | | | | |
| 1965 | 194 | | | | | | | | | | | | | |
| 1966 | 154 | | | | | | | | | | | | | |
| 1967 | 131 | | | | | | | | | | | | | |
| 1968 | 96.9 | | | | | | | | | | | | | |
| 1969 | 98.3 | | | | | | | | | | | | | |
| 1970 | 109 | | | | | | | | | | | | | |
| 1971 | 66.7 | | | | | | | | | | | | | |
| 1972 | 122 | | | | | | | | | | | | | |
| 1973 | 301 | | | | | | | | | | | | | |
| 1974 | 182 | | | | | | | | | | | | | |
| 1975 | 340 | | | | | | | | | | | | | |
| 1976 | 423 | | | | | | | | | | | | | |
| 1977 | 409 | | | | | | | | | | | | | |
| 1978 | 319 | | | | | | | | | | | | | |
| 1979 | 406 | | | | | | | | | | | | | |
| 1980 | 601 | | | | | | | | | | | | | |
| 1981 | 564 | | | | | | | | | | | | | |
| 1982 | 522 | | | | | | | | | | | | | |
| 1983 | 592 | | 12 | 12 | 12 | 12 | 4 | 17 | 17 | 17 | 3.0 | 4.7 | 7.0 | 9.3 |
| 1984 | 727 | | 12 | 8.7 | 13 | 17.3 | 4 | 12.0 | 18 | 24.0 | 3.0 | 6.7 | 10.0 | 13.3 |
| 1985 | 1297 | | 12 | 9.3 | 14 | 18.7 | 4 | 12.7 | 19 | 25.3 | 3.0 | 8.0 | 12.0 | 16.0 |
| 1986 | 598 | | 12 | 10.0 | 15 | 20.0 | 4 | 13.3 | 20 | 26.7 | 3.0 | 9.3 | 14.0 | 18.6 |
| 1987 | 598 | | 12 | 10.7 | 16 | 21.3 | 4 | 14.0 | 21 | 28.0 | 3.0 | 10.7 | 16.0 | 21.3 |
| 1988 | 470 | | 12 | 11.3 | 17 | 22.7 | 4 | 14.7 | 22 | 29.3 | 3.0 | 12.0 | 18.0 | 23.9 |
| 1989 | 572 | 1 | 12 | 12.0 | 18 | 24.0 | 4 | 15.3 | 23 | 30.7 | 3.3 | 13.3 | 20.0 | 26.6 |
| 1990 | 541 | 1.03 | 12 | 12.0 | 18 | 24.0 | 4 | 16.0 | 24 | 32.0 | 3.3 | 15.3 | 23.0 | 30.6 |
| 1991 | 526 | 0.95 | 12 | 12.7 | 19 | 25.3 | 4 | 16.7 | 25 | 33.3 | 3.3 | 16.7 | 25.0 | 33.3 |
| 1992 | 464 | 1.09 | 12 | 12.7 | 19 | 25.3 | 4 | 17.3 | 26 | 34.7 | 3.3 | 20.0 | 30.0 | 39.9 |
| 1993 | 588 | 1.22 | 9.0 | 13.3 | 20 | 26.7 | 4 | 18.0 | 27 | 36.0 | 3.3 | 26.7 | 40.0 | 53.2 |
| 1994 | 530 | 0.94 | 5.1 | 13.3 | 20 | 26.7 | 4 | 18.7 | 28 | 37.3 | 2.3 | 33.4 | 50.0 | 66.5 |
| 1995 | 519 | 1.12 | 12.8 | 13.3 | 20 | 26.7 | 4 | 19.3 | 29 | 38.7 | 8.5 | 42.0 | 63.0 | 83.8 |
| 1996 | 528 | 0.91 | 15.6 | 12.0 | 18 | 24.0 | 4 | 20.0 | 30 | 40.0 | 4.5 | 36.7 | 55.0 | 73.2 |
| 1997 | 585 | 0.88 | 12.4 | 10.0 | 15 | 20.0 | 4 | 20.0 | 30 | 40.0 | 3.2 | 20.0 | 30.0 | 39.9 |
| 1998 | 642 | 1.01 | 4.8 | 12 | 12 | 12 | 0.5 | 30 | 30 | 30 | 0.4 | 3.0 | 3.0 | 3.0 |
| 1999 | 565 | 0.87 | 0.7 | 11 | 11 | 11 | 0.3 | 25 | 25 | 25 | 0 | 0 | 0 | 0 |
| 2000 | 574 | 0.93 | 1.7 | 10 | 10 | 10 | 0.3 | 20 | 20 | 20 | 0 | 0 | 0 | 0 |
| 2001 | 569 | 0.90 | 2.5 | 8 | 8 | 8 | 0.3 | 23 | 23 | 23 | 0 | 0 | 0 | 0 |
| 2002 | 601 | 0.79 | 1.8 | 15 | 15 | 15 | 0.3 | 19 | 19 | 19 | 0 | 0 | 0 | 0 |
| 2003 | 524 | 0.64 | 1.6 | 6.2 | 6.2 | 6.2 | 0 | 1.5 | 1.5 | 1.5 | 0.3 | 3.2 | 3.2 | 3.2 |
| 2004 | 385 | 0.64 | 2 | 8.2 | 8.2 | 8.2 | 0.1 | 0.9 | 0.9 | 0.9 | 0.1 | 2.8 | 2.8 | 2.8 |
| 2005 | 365 | 0.69 | 0.8 | 4.8 | 4.8 | 4.8 | 0 | 2.3 | 2.3 | 2.3 | 0.1 | 1.8 | 1.8 | 1.8 |
| 2006 | 392 | 0.83 | 1.7 | 5.4 | 5.4 | 5.4 | 0 | 2 | 2 | 2 | 0.2 | 3.5 | 3.5 | 3.5 |
| 2007 | 369 | 0.75 | 1 | 3.8 | 3.8 | 3.8 | 0 | 1.6 | 1.6 | 1.6 | 0.1 | 4.0 | 4.0 | 4.0 |
| 2008 | 303 | 0.86 | 0 | 15 | 15 | 15 | 0 | 5 | 5 | 5 | 0 | 15 | 15 | 15 |

**Table 6.3.3.** Age-composition data for Denham Sound (A), Freycinet Estuary (B), Eastern Gulf (C) and oceanic (D) pink snapper stocks. n = total number of samples aged in each year.

| | | | Age (years) | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | y | n | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26+ |
| A | 1997 | 69 | 0 | 0 | 1 | 18 | 19 | 10 | 8 | 10 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 1998 | 147 | 0 | 0 | 0 | 2 | 20 | 35 | 23 | 19 | 30 | 13 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 1999 | 86 | 0 | 0 | 4 | 6 | 10 | 7 | 6 | 10 | 9 | 15 | 6 | 2 | 3 | 1 | 2 | 4 | 0 | 0 | 0 | 1 | 0 | | | | | | |
| | 2000 | 252 | 0 | 0 | 11 | 19 | 36 | 64 | 31 | 33 | 17 | 17 | 13 | 4 | 5 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 2001 | 67 | 0 | 0 | 8 | 16 | 8 | 16 | 5 | 4 | 1 | 3 | 3 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 2003 | 107 | 0 | 0 | 0 | 0 | 11 | 23 | 32 | 14 | 11 | 2 | 2 | 1 | 1 | 3 | 2 | 0 | 1 | 1 | 2 | 1 | 0 | | | | | | |
| B | 1997 | 86 | 0 | 0 | 10 | 0 | 0 | 1 | 6 | 19 | 11 | 1 | 2 | 4 | 0 | 4 | 2 | 2 | 4 | 0 | 5 | 1 | 1 | 2 | 1 | 0 | 2 | 2 | 6 |
| | 1998 | 64 | 0 | 0 | 4 | 0 | 0 | 0 | 1 | 6 | 17 | 15 | 5 | 0 | 2 | 2 | 2 | 2 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 1 | 0 | 2 |
| | 1999 | 127 | 0 | 0 | 2 | 9 | 6 | 6 | 8 | 4 | 7 | 41 | 13 | 4 | 2 | 2 | 1 | 5 | 1 | 0 | 0 | 2 | 3 | 1 | 4 | 0 | 2 | 0 | 4 |
| | 2000 | 181 | 0 | 0 | 5 | 13 | 27 | 18 | 6 | 20 | 5 | 9 | 23 | 22 | 9 | 0 | 5 | 4 | 2 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 4 | 4 |
| | 2001 | 66 | 0 | 0 | 0 | 3 | 7 | 21 | 7 | 0 | 3 | 1 | 3 | 12 | 4 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2002 | 81 | 0 | 0 | 0 | 0 | 0 | 4 | 11 | 13 | 2 | 5 | 2 | 2 | 19 | 7 | 1 | 0 | 2 | 2 | 1 | 2 | 2 | 0 | 1 | 2 | 1 | 0 | 2 |
| | 2004 | 119 | 0 | 0 | 4 | 0 | 6 | 8 | 7 | 39 | 34 | 13 | 1 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | 2006 | 106 | 0 | 0 | 0 | 0 | 1 | 1 | 13 | 13 | 8 | 26 | 22 | 3 | 1 | 1 | 2 | 1 | 5 | 3 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| | 2007 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 18 | 8 | 12 | 25 | 20 | 9 | 4 | 1 | 0 | 4 | 3 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 2 |
| C | 1998 | 113 | 0 | 0 | 2 | 12 | 6 | 7 | 27 | 32 | 12 | 7 | 6 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 1999 | 81 | 0 | 0 | 0 | 3 | 10 | 9 | 12 | 14 | 16 | 8 | 5 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 2000 | 265 | 0 | 0 | 29 | 47 | 46 | 29 | 16 | 25 | 37 | 23 | 7 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 2001 | 104 | 0 | 0 | 4 | 16 | 14 | 12 | 7 | 7 | 8 | 16 | 6 | 6 | 3 | 2 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | | | | | | |
| | 2002 | 103 | 0 | 0 | 0 | 3 | 10 | 18 | 21 | 30 | 9 | 3 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | | | | | | |
| | 2003 | 186 | 0 | 0 | 10 | 26 | 41 | 22 | 15 | 23 | 25 | 8 | 4 | 6 | 4 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | 2004 | 250 | 0 | 0 | 4 | 6 | 20 | 26 | 33 | 24 | 50 | 35 | 15 | 8 | 11 | 7 | 7 | 2 | 2 | 0 | 0 | 0 | 0 | | | | | | |
| D | 1992 | 200 | 0 | 0 | 4 | 27 | 66 | 35 | 25 | 22 | 10 | 5 | 2 | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1996 | 557 | 0 | 0 | 0 | 15 | 43 | 150 | 157 | 108 | 38 | 12 | 6 | 11 | 4 | 4 | 1 | 4 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 1999 | 88 | 0 | 0 | 0 | 0 | 5 | 8 | 15 | 13 | 11 | 11 | 5 | 3 | 1 | 4 | 5 | 2 | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2001 | 242 | 0 | 0 | 5 | 10 | 16 | 18 | 28 | 17 | 22 | 27 | 29 | 20 | 10 | 10 | 7 | 7 | 3 | 3 | 2 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 |
| | 2003 | 201 | 0 | 0 | 4 | 26 | 38 | 26 | 18 | 13 | 7 | 5 | 16 | 10 | 12 | 4 | 3 | 3 | 2 | 4 | 2 | 4 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| | 2004 | 609 | 0 | 0 | 2 | 88 | 128 | 127 | 86 | 45 | 33 | 14 | 16 | 14 | 24 | 11 | 4 | 1 | 5 | 1 | 2 | 3 | 2 | 1 | 1 | 0 | 1 | 0 | 0 |
| | 2005 | 497 | 0 | 0 | 12 | 53 | 116 | 155 | 77 | 40 | 20 | 5 | 5 | 4 | 2 | 0 | 2 | 0 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2006 | 688 | 0 | 0 | 15 | 30 | 59 | 155 | 176 | 126 | 69 | 24 | 10 | 6 | 3 | 3 | 2 | 4 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| | 2007 | 336 | 0 | 0 | 1 | 17 | 73 | 58 | 63 | 40 | 34 | 22 | 8 | 4 | 5 | 1 | 4 | 2 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | 2008 | 685 | 0 | 0 | 5 | 59 | 152 | 117 | 102 | 82 | 53 | 37 | 25 | 19 | 11 | 5 | 0 | 0 | 5 | 1 | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 0 | 5 |

**Table 6.3.4.** Ogive of sexual maturity for pink snapper, $P_{s,a}$ , for sex, *s* and age, $a$ , for inner gulf stocks, Denham Sound (A), Freycinet Estuary (B), and Eastern Gulf (C) derived from the values of *L*50 and *L*95 for males and females shown (fork length, mm). For the oceanic stock (D), the spawning biomass of females only was determined.

| | *L*50 | *L*95 | $a$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | >15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 400 | 600 | $p_{f,a}$ | 0.000 | 0.013 | 0.044 | 0.123 | 0.269 | 0.460 | 0.638 | 0.768 | 0.851 | 0.902 | 0.933 | 0.952 | 0.970 | 0.980 | 1 | 1 | 1 |
| | 600 | 400 | $p_{m,a}$ | 0.004 | 0.039 | 0.227 | 0.623 | 0.881 | 0.965 | 0.988 | 0.996 | 0.998 | 0.999 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| B | 420 | 420 | $p_{f,a}$ | 0.000 | 0.006 | 0.036 | 0.150 | 0.399 | 0.671 | 0.841 | 0.922 | 0.959 | 0.977 | 0.985 | 0.990 | 0.970 | 0.980 | 1 | 1 | 1 |
| | 570 | 570 | $p_{m,a}$ | 0.000 | 0.006 | 0.036 | 0.150 | 0.399 | 0.671 | 0.841 | 0.922 | 0.959 | 0.977 | 0.985 | 0.990 | 0.970 | 0.980 | 1 | 1 | 1 |
| C | 350 | 240 | $p_{f,a}$ | 0.000 | 0.021 | 0.152 | 0.515 | 0.824 | 0.942 | 0.979 | 0.991 | 0.996 | 0.998 | 0.999 | 0.999 | 0.970 | 0.980 | 1 | 1 | 1 |
| | 480 | 400 | $p_{m,a}$ | 0.041 | 0.251 | 0.652 | 0.888 | 0.964 | 0.986 | 0.994 | 0.997 | 0.998 | 0.999 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| D | 320 | 430 | $p_{f,a}$ | 0.063 | 0.283 | 0.628 | 0.849 | 0.939 | 0.972 | 0.986 | 0.992 | 0.995 | 0.996 | 0.997 | 0.998 | 0.998 | 1.000 | 1 | 1 | 1 |

**Table 6.3.5.** von Bertalanffy growth parameters ($L\infty$, $k$ , $to$ ) and parameters of the length-weight relationship used to determine weight-at-age for Denham Sound (A), Freycinet Estuary (B), and Eastern Gulf (C) and oceanic stock (D). Lengths are fork length (mm). F = females, M = males

| | | $L\infty$ | $k$ | $to$ | Weight coefficient | Weight power |
|---|---|---|---|---|---|---|
| A | F | 762 | 0.142 | -0.032 | 1.480E-04 | 2.67 |
| | M | 660 | 0.18 | -0.055 | 1.480E-04 | 2.67 |
| B | F | 773 | 0.166 | 0.125 | 1.480E-04 | 2.67 |
| | M | 766 | 0.173 | 0.075 | 1.480E-04 | 2.67 |
| C | F | 755 | 0.178 | 0.035 | 1.480E-04 | 2.67 |
| | M | 751 | 0.172 | -0.071 | 1.480E-04 | 2.67 |
| D | F | 598 | 0.214 | -0.144 | 7.410E-08 | 2.79 |
| | M | 561 | 0.244 | -0.079 | 7.410E-08 | 2.79 |

**Table 6.3.6.** DEPM-based estimates of spawning biomass (weight [tonnes] of sexually mature males and females, ( $D_y$ ) and the standard deviation ($\sigma_{D_y}$ ), for the three inner gulf stocks from DEPM surveys conducted 1997-2007.

| | Denham Sound | | Freycinet Estuary | | Eastern Gulf | |
|---|---|---|---|---|---|---|
| | $D_y$ | $\sigma_{D_y}$ | $D_y$ | $\sigma_{D_y}$ | $D_y$ | $\sigma_{D_y}$ |
| 1997 | - | - | - | - | 12 | 4 |
| 1998 | 176 | 106 | 195 | 123 | 25 | 8 |
| 1999 | 10 | 2 | 32 | 7 | 59 | 14 |
| 2000 | 184 | 73 | 87 | 20 | 232 | 54 |
| 2001 | 70 | 29 | 14 | 5 | 96 | 33 |
| 2002 | 125 | 34 | 27 | 9 | 62 | 25 |
| 2003 | 92 | 19 | - | - | 181 | 79 |
| 2004 | - | - | 9 | 2 | 59 | 14 |
| 2005 | - | - | - | - | - | - |
| 2006 | - | - | 52 | 12 | - | - |
| 2007 | - | - | 30 | 10 | - | - |

**Table 6.3.7.** The selectivity of pink snapper to fishing $v_a$ , at age, $a$ , for Denham Sound (A), Freycinet Estuary (B), and Eastern Gulf (C) and the oceanic stock (D). The vulnerability changed in 2001 in Area A, B, and C due to the introduction of a new minimum and maximum legal lengths. Minimum legal length for oceanic stock was taken as constant at 41 cm since 1952.

| $a$ | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | >15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | $v_a$ | <2001 | 0 | 0 | 0 | 0.065 | 0.385 | 0.763 | 0.827 | 0.987 | 0.944 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | | ≥2001 | 0 | 0 | 0 | 0 | 0.108 | 0.356 | 0.693 | 0.827 | 0.889 | 0.853 | 0.929 | 0.75 | 0.5 | 0.12 | 0 | 0 | 0 |
| B | $v_a$ | <2001 | 0 | 0 | 0 | 0.065 | 0.385 | 0.75 | 0.86 | 0.987 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | | ≥2001 | 0 | 0 | 0 | 0 | 0.108 | 0.356 | 0.693 | 0.88 | 0.97 | 0.99 | 0.94 | 0.75 | 0.5 | 0.12 | 0 | 0 | 0 |
| C | $v_a$ | <2001 | 0 | 0 | 0 | 0.065 | 0.385 | 0.763 | 0.89 | 0.97 | 0.98 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | | ≥2001 | 0 | 0 | 0 | 0 | 0.108 | 0.356 | 0.693 | 0.898 | 0.96 | 1 | 0.929 | 0.75 | 0.5 | 0.12 | 0 | 0 | 0 |
| D | $v_a$ | ≥1952 | 0 | 0.007 | 0.041 | 0.215 | 0.635 | 0.917 | 0.986 | 0.998 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Table 6.3.8.** Parameter estimates with standard deviations. Recruitment, $R_y$ (sd = $\sigma_{R_y}$); log normal recruitment, $\varepsilon_y$ (sd = $\sigma_y$); natural mortality, $M$ (sd = $\sigma_M$); natural log catchability, $q$ (sd = $\sigma_q$); parameters of selectivity ogive, $V_{50}$and $V_{95}$(sd = s $V_{50}$, s $V_{95}$); and steepness, *h*. The values without standard deviations are fixed values in the model.

| Oceanic | | | Denham Sound | | | | | | Freycinet Estuary | | | | | | Eastern Gulf | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Low | | Medium | | High | | Low | | Medium | | High | | Low | | Medium | | High | |
| | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ | $R_y$ | $\sigma_{R_y}$ |
| | 6.53 | 0.05 | 19.34 | 0.56 | 23.34 | 0.69 | 27.29 | 0.83 | 13.37 | 0.30 | 16.58 | 0.36 | 19.73 | 0.42 | 13.79 | 0.45 | 19.34 | 0.65 | 24.8 | 0.84 |
| | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $\sigma_y$ | $\varepsilon_y$ | $s_y$ | $\varepsilon_y$ | $s_y$ |
| 1983 | | | -0.38 | 0.37 | -0.31 | 0.38 | -0.26 | 0.38 | 0.55 | 0.17 | 0.66 | 0.17 | 0.75 | 0.18 | -0.38 | 0.31 | -0.35 | 0.31 | -0.34 | 0.31 |
| 1984 | | | -0.08 | 0.34 | 0.00 | 0.34 | 0.06 | 0.34 | 0.35 | 0.17 | 0.44 | 0.17 | 0.51 | 0.17 | -0.51 | 0.31 | -0.48 | 0.31 | -0.47 | 0.31 |
| 1985 | | | -0.87 | 0.38 | -0.81 | 0.38 | -0.75 | 0.38 | 0.44 | 0.16 | 0.52 | 0.16 | 0.58 | 0.16 | -0.25 | 0.3 | -0.23 | 0.3 | -0.21 | 0.3 |
| 1986 | | | -0.61 | 0.33 | -0.55 | 0.33 | -0.50 | 0.33 | -0.04 | 0.17 | 0.03 | 0.17 | 0.08 | 0.17 | -0.5 | 0.3 | -0.47 | 0.3 | -0.46 | 0.3 |
| 1987 | | | -0.27 | 0.27 | -0.22 | 0.27 | -0.18 | 0.27 | 0.24 | 0.15 | 0.29 | 0.15 | 0.34 | 0.15 | 0.43 | 0.24 | 0.46 | 0.24 | 0.48 | 0.24 |
| 1988 | | | 0.26 | 0.19 | 0.28 | 0.19 | 0.30 | 0.19 | 1.00 | 0.11 | 1.02 | 0.11 | 1.05 | 0.11 | 0.34 | 0.21 | 0.37 | 0.21 | 0.38 | 0.21 |
| 1989 | | | 0.83 | 0.13 | 0.82 | 0.13 | 0.81 | 0.13 | 1.38 | 0.09 | 1.37 | 0.09 | 1.37 | 0.09 | 0.45 | 0.16 | 0.46 | 0.16 | 0.46 | 0.16 |
| 1990 | | | 0.14 | 0.14 | 0.08 | 0.14 | 0.04 | 0.14 | 0.11 | 0.12 | 0.10 | 0.12 | 0.10 | 0.12 | 0.41 | 0.11 | 0.39 | 0.11 | 0.37 | 0.11 |
| 1991 | | | -0.13 | 0.13 | -0.22 | 0.13 | -0.29 | 0.13 | -0.45 | 0.14 | -0.47 | 0.13 | -0.49 | 0.13 | -0.27 | 0.1 | -0.31 | 0.1 | -0.34 | 0.1 |
| 1992 | 0.36 | 0.11 | -0.07 | 0.11 | -0.19 | 0.11 | -0.28 | 0.11 | -0.21 | 0.12 | -0.28 | 0.12 | -0.34 | 0.11 | -1.46 | 0.12 | -1.52 | 0.13 | -1.56 | 0.13 |
| 1993 | 0.03 | 0.12 | -0.25 | 0.12 | -0.38 | 0.12 | -0.48 | 0.12 | -0.59 | 0.13 | -0.68 | 0.13 | -0.76 | 0.12 | -1.73 | 0.13 | -1.78 | 0.13 | -1.81 | 0.13 |
| 1994 | -0.03 | 0.12 | -0.10 | 0.12 | -0.20 | 0.12 | -0.29 | 0.13 | 0.02 | 0.10 | -0.11 | 0.09 | -0.21 | 0.09 | -1.02 | 0.12 | -1.06 | 0.12 | -1.08 | 0.12 |
| 1995 | -0.23 | 0.14 | 0.12 | 0.14 | 0.05 | 0.14 | -0.02 | 0.14 | 0.48 | 0.08 | 0.35 | 0.08 | 0.25 | 0.08 | -0.52 | 0.12 | -0.55 | 0.12 | -0.56 | 0.12 |
| 1996 | -0.23 | 0.14 | 0.85 | 0.17 | 0.82 | 0.17 | 0.79 | 0.17 | 0.29 | 0.09 | 0.21 | 0.09 | 0.14 | 0.09 | -0.05 | 0.12 | -0.06 | 0.12 | -0.07 | 0.12 |
| 1997 | -0.31 | 0.13 | 1.51 | 0.23 | 1.55 | 0.23 | 1.59 | 0.23 | -0.63 | 0.12 | -0.66 | 0.12 | -0.67 | 0.12 | 0.77 | 0.12 | 0.8 | 0.12 | 0.83 | 0.12 |
| 1998 | -0.24 | 0.12 | 1.29 | 0.28 | 1.34 | 0.28 | 1.38 | 0.28 | -0.70 | 0.12 | -0.70 | 0.12 | -0.69 | 0.12 | 1.09 | 0.14 | 1.1 | 0.14 | 1.1 | 0.14 |
| 1999 | -0.03 | 0.11 | -0.74 | 0.48 | -0.68 | 0.48 | -0.64 | 0.48 | -0.49 | 0.12 | -0.48 | 0.12 | -0.47 | 0.12 | 1.57 | 0.17 | 1.58 | 0.17 | 1.59 | 0.17 |
| 2000 | 0.12 | 0.09 | -0.74 | 0.48 | -0.68 | 0.48 | -0.64 | 0.48 | -0.84 | 0.15 | -0.81 | 0.15 | -0.78 | 0.15 | 1.56 | 0.34 | 1.57 | 0.34 | 1.57 | 0.34 |
| 2001 | 0.26 | 0.09 | -0.74 | 0.48 | -0.68 | 0.48 | -0.64 | 0.48 | -0.59 | 0.15 | -0.55 | 0.15 | -0.52 | 0.15 | 0.08 | 0.34 | 0.09 | 0.34 | 0.1 | 0.34 |
| 2002 | 0.21 | 0.09 | | | | | | | -0.32 | 0.17 | -0.27 | 0.17 | -0.23 | 0.17 | | | | | | |
| 2003 | -0.11 | 0.10 | | | | | | | | | | | | | | | | | | |
| 2004 | 0.00 | 0.11 | | | | | | | | | | | | | | | | | | |
| 2005 | 0.16 | 0.12 | | | | | | | | | | | | | | | | | | |
| 2006 | 0.09 | 0.14 | | | | | | | | | | | | | | | | | | |
| 2007 | -0.01 | 0.16 | | | | | | | | | | | | | | | | | | |
| 2008 | -0.03 | 0.18 | | | | | | | | | | | | | | | | | | |
| | $M$ | $\sigma_M$ | | | | | | | | | | | | | | | | | | |
| | 0.138 | 0.003 | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - | 0.11 | - |
| | $V_{50}$ | $\sigma_{V_{50}}$ | | | | | | | | | | | | | | | | | | |
| | 3.701 | 0.142 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | $V_{95}$ | $\sigma_{V_{95}}$ | | | | | | | | | | | | | | | | | | |
| | 5.290 | 0.305 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | $q$ | $\sigma_q$ | | | | | | | | | | | | | | | | | | |
| | -7.98 | 0.16 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| h | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - | 0.75 | - |

### 6.3.2.2 Fishing mortality assessments: Spangled emperor, Goldband snapper

Data on the retained catch-at-lengths of each stock were presented for each sector for comparative purposes, in order to visually assess potential differences in fishing mortality on population size structure among the different sectors. Logistic selectivity models were fitted to age frequency data up to and including the modal age to quantify fishing mortality effects due to gear selectivity. Catch curve analyses were done to estimate the level of total mortality ($Z$) (and by subtracting estimated natural mortality coefficient ($M$), the fishing mortality ($F$)) on fish population age structures. Estimates of $F$ were then related to $M$ and reference levels for management (Wise *et al.* 2007). Yield per recruit and egg per recruit analyses were done to demonstrate the potential for growth and recruitment overfishing, respectively, given the biological parameters presented in Sections 5.2 and 5.3, and under a range of potential values of $F$.

#### 6.3.2.2.1 Catch size structure and selectivity analyses

Although biological catch samples of spangled emperor were available from the charter sector in 2006-2008 (Table 5.2.1), these were collected opportunistically for the purpose of supplementing monthly biological samples rather than for the explicit purpose of obtaining representative biological samples of the landed catches for that sector. So, for the purpose of the sector-specific comparisons of landed fish length distributions, catch-at-length data for spangled emperor and goldband snapper were obtained from length measurements recorded by charter fishers on statutory daily/trip logbook returns (see Section 4.3), as these data were considered to provide a better representation of the catch-at-length distribution for the sector.

The gear selectivity (or availability, if fish are not on the fished grounds) of younger age classes to capture by line fishing by sector was also described from an analysis of catch-at-length data of fish caught, including fish caught and released. Recreational catch at length data for spangled emperor from RAP logbook data and commercial catch at length for goldband snapper from biological sampling of landed catches were used for gear selectivity modelling because there was no exclusion of fish below the minimum legal size limits (MLL) for either of those data sets. For the purpose of calculating selectivity coefficients, catch at length data ($l$) were converted into catch at age data ($\hat{t}$) using the inverse of the von Bertalanffy growth function:

$$\hat{t} = t_0 - \frac{ln\left(1 - \frac{l}{L_\infty}\right)}{K}$$

where $L_\infty$, $K$ and $t_0$ were fitted parameters of the von Bertalanffy growth model. The von Bertalanffy growth parameters used for goldband snapper are in Table 6.3.10. The von Bertalanffy growth parameters used for spangled emperor were obtained by re-fitting the von Bertalanffy model to total length (TL: mm) at age data for the entire Bioregion pooled across sexes, to be consistent with $l$ data available from the RAP logbooks (i.e., TL, no sex information: $L_\infty$ = 664.6 mm TL; $K$ = 0.241 yr$^{-1}$; $t_0$= -0.375 yr; n = 1,751; $r^2$ = 0.80). Selectivity coefficients were only calculated for fish younger than the age of full recruitment to the fishery (Ricker 1969) ($t_r$). The $t_r$ was determined as the modal age of the calculated $\hat{t}$ distribution. All fish older than or the same age as $t_r$ were assumed to be fully recruited and thus assigned selectivity coefficient values ($s_t$) of 1. Therefore, predictions of age from $l$ data for the purpose of calculating $s_t$ were only done for fish younger than $t_r$, which was considered valid because $t_r$ was well below the age range of observed asymptotic growth for both species.

The $s_t$ values for age classes younger than $t_r$ were calculated as the ratio of observed catch frequency divided by the frequency expected to have encountered fishing gear ($\zeta$). Expected frequencies of $\zeta$ were approximated by back-calculating from $t_r$ the number of fish expected to be caught in the sample given the estimated natural mortality (*M)* and the observed catch frequency at age $t_r$:

for $\hat{t} = t_{r\text{-}1}$: $$\zeta_{t_r-1} = \frac{\zeta_{t_r}}{e^{-M}}$$

for all $\hat{t} < t_{r\text{-}1}$: $$\zeta_{t-1} = \frac{\eta_t}{e^{-M}}$$

where;

$\zeta_{t_r}$ = the observed catch frequency of age $t_r$ fish, which was used to scale expected frequencies of fish younger than $t_r$, given the assumed natural mortality function, to those that would correspond to a representative sample from the population;

$\eta_t$ = the frequency in the catch of age $\hat{t}$.

A logistic model was then fitted to the $s_t$ data:

for all $t \le t_r$ : $$\hat{s}_t = \frac{1}{1+e^{(a\_select \times t)+b\_select}}$$

where;

*a*_select = model parameter;

*b*_select = model parameter.

#### 6.3.2.2.2 Catch curve analyses

Prior to catch curve analyses, age frequency data were assessed for acceptable precision by calculating precision index values according to the following formula: Precision = $D / \sqrt{n}$ . For the 95% confidence level *D* was equal to 1.358 and the target range of precision was between 0.04 and 0.08 (Craine *et al*. 2009). This value represents how well a sampled age frequency distribution will reflect the shape of the population age frequency distribution from which it was sampled, in the absence of sampling bias (Craine *et al.* 2009).

The 2007/08 representative catch-at-age distributions of spangled emperor caught by the recreational sector from the North Gascoyne and South Gascoyne regions (Fig. 5.2.4) and the 2005/06 and 2007/08 representative catch-at-age distributions of goldband snapper caught by the commercial sector from the South Gascoyne (Fig. 5.3.4) were used to estimate the instantaneous total mortality rate, *Z,* by fitting three different catch-curve models to these data (Table 6.3.9). These three catch curve models were developed for and used in previous stock assessments of similar long-lived temperate demersal scalefish species (Wise *et al.* 2007). Model I was a linear regression fitted to each $\log_e$ transformed age frequency distribution, from the age class following the modal age to the oldest age class prior to a sample frequency of zero. Model II was also a linear model fitted to $\log_e$ transformed age frequency distributions, however the fitting was done using a robust piecewise log-linear regression of relative age frequency (plus a small constant, 1/n), from the median age to *t** (the oldest *t* to which the model was fitted). The slope parameter was estimated by minimising the absolute deviation of the negative log-likelihood of the Laplacian error terms while iteratively searching for optimisation of the piecewise regression at *t** (Wise et al., 2007). Model III estimated the numbers-at-age caught from the starting number at age 0 ($N_0$), sampling selectivity shape parameters (*A*50*, A*95) and an input for the instantaneous rate of natural mortality, $M$ (see below), by fitting the model to the non-zero untransformed sampled age frequencies (Wise *et al.,* 2007).

**Table 6.3.9.** Models for estimating instantaneous rates of total mortality ($Z$). $N_t$ and $P_t$ is the number and percentage of spangled emperor sampled at age ($t$) years, respectively. $t_{median}$, $t^*$ and $t_{\max}$ is the median, maximum fitted, and maximum observed $t$, respectively. Models from Wise *et al.* (2007).

| Method | Model |
|---|---|
| I | $\ln(N_t) = \ln(N_0) + Z_1 t$ |
| II | $\ln(P_t) = \begin{cases} \log_e\left(P_0 + 1/\sum N_t\right) - Z_2 t \ldots (t_{median} < t < t^*) \\ \log_e(1/\sum N_t) \ldots\ldots\ldots\ldots\ldots\ldots (t \geq t^*) \end{cases}$ |
| III | $N_{t+1} = N_t \left(\frac{s_t F}{M + s_t F}\right)\left(1 - e^{-(M + s_t F)}\right)$ ; $Z_3 = F + M$ <br> where: <br> $s_t = 1/(1+e^{\ln(19)(A50-t)(A95-A50)})$ |

Sampled catch at age data were randomly re-sampled with replacement (i.e. bootstrapped) 10,000 times prior to refitting each of the three models to generate bootstrapped estimates of $Z$ for each study region (North Gascoyne, South Gascoyne), year and species (Efron 1982). Bias-adjusted 95% confidence intervals about deterministic estimates of $Z$ (i.e., $M$ + fishing mortality, $F$) were calculated from the bootstrapped estimates using the bias adjustment formulas of Haddon (2001). To explore the potential influence of decisions made to group age data by specific year type (i.e., recreational, commercial, calendar; see Fig. 4.1), catch curve and bootstrapping analyses were repeated for different year type groupings (i.e., spangled emperor: calendar, commercial years; goldband snapper: calendar, recreational years, where sufficient data were available) and results compared.

An estimate of $M$ and bias-adjusted 95% confidence bounds about this estimate for spangled emperor in the North and South Gascoyne were obtained from Marriott *et al.* (2011a). An estimate of $M$ was obtained for goldband snapper using the published findings of Newman and Dunk (2003), who reported a range of $M$ estimates for the Kimberley stock. Since no reliable estimate of $M$ was available for the exploited Gascoyne stock, it is assumed that this range of estimates reported by Newman and Dunk (2003) is also suitable to use for the Gascoyne stock.

Ratios of $F$: $M$ were then calculated as a performance indicator for the stocks. These ratios were related to pre-determined reference levels developed by the DoFWA for demersal scalefish species with intermediate and long life spans (longevity exceeding 10 yr) as an objective criterion for informing fisheries management decisions: $F_{\text{Target}}$ = 2/3 $M$; $F_{\text{Threshold}} = M$; $F_{\text{Limit}}$ = 1.5 $M$ (Wise et al. 2007), with the management objective to keep the $F$ to less than the $F_{\text{Threshold}}$.

The fit of catch curve models to catch-at-age data for spangled emperor sampled from the North Gascoyne and South Gascoyne regions, an evaluation of those model fits, and estimation of $M$ for those stocks is published in Marriott *et al*. (2011a). Reproduction of estimates of $Z$, $F$ and $M$ for these spangled emperor stocks is therefore limited here to the presentation of parameter estimates and 95% confidence limits about those estimates as they pertain to this Level 3 weight of evidence assessment.

#### 6.3.2.2.3 Per-recruit analyses

Yield per recruit (YPR) was calculated as:

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

and egg per recruit (EPR) was calculated as:

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

where:

$N_t$ is the population size at age $t$ calculated from

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

$F$ is fishing mortality

*sex* is either female or male

$w_{sex,t}$ is the average weight at age $t$

$Pmat_t$ is the proportion of females mature at age $t$ (from Marriott et al. (2010))

$fec_t$ is the batch fecundity at age $t$

$Psexchange_t$ is the proportion changing sex at age $t$

$N_{sex,0}$ is initial proportion of females at age 0 years

$S_{sex,t}$ is fishing selectivity at age $t$ for each *sex* and calculated by either:

(i) (spangled emperor*:* MLL) assuming knife-edged selectivity at the age $t$ corresponding to MLL:

$S_{sex,t} = 1$ for $t > t_{\mathrm{MLL}}$

$S_{sex,t} = 0$ for $t \leq t_{\mathrm{MLL}}$

where $t_{\mathrm{MLS}}$ is the average age $t$ at MLL, rounded down to the nearest whole integer, or;

(ii) (goldband snapper: *No MLL*) Fitting a logistic model to empirical selectivity (or availability, if younger fish are not on the fished grounds) coefficients for age classes up to (but excluding) the modal age (inferred $t_r$), as described above. In addition, the YPR and EPR for goldband snapper was calculated for $F_{\mathrm{target}}$, $F_{\mathrm{threshold}}$ and $F_{\mathrm{limit}}$ for a range of different values of age at selectivity, using (for simplicity) a knife-edged selectivity function. This was done to explore the potential influence of a change in selectivity pattern from the current one described for goldband snapper because very few young goldband snapper are caught and there is no MLL for this species.

Parameter inputs for the YPR and EPR analyses are listed in Table 6.3.10. Importantly, the per-recruit analyses represent very simplistic predictions of how spangled emperor and goldband snapper populations might respond to fishing mortality, and ignore the potential influence of many other important aspects of population dynamics, such as the relationship between spawning stock size and subsequent recruitment, annual recruitment variability, environmental changes and other external influences. Both the per-recruitment and catch curve analyses do not assess data sampled from the stock over time, and so cannot model or test for such processes to account for their influence(s) on estimates of stock status and inferred inherent vulnerability.

**Table 6.3.10.** Parameter inputs for per-recruit analyses. t = age (years); FL = length to caudal fork (mm); $\overline{X}_{fec/g}$ = mean batch fecundity (eggs) per gram of body weight. Selectivity / availability function used for goldband snapper in place of tr because no MLL in place for that species.

| Species | Input | Equation / estimate | Source / Section |
|---|---|---|---|
| *Goldband snapper* | *M* | 0.121 | Newman and Dunk (2003) |
| | $t_r$ | 8 yr | 5.3.2.3.4 |
| | MLL, $t_{MLS}$ | n/a | - |
| | $S_{sex,t}$ | (i). $\dfrac{1}{1+e^{(a\_select \times t)+b\_select}}$<br>(ii) Knife-edged (0,1) for a range of different ages (1 – $t_{max}$) at selectivity. | Current pattern: This section. |
| | $fec_t$ | $w_{female,t}$ | - |
| | $Pmat_t$ | $\dfrac{1}{1+e^{-0.0442(FL_t-473)}}$ | Newman *et al.* (2001) |
| | $w_{sex,t}$ | $2.825*10^{-5}FL_t^{2.928}$ | Newman and Dunk (2003) |
| | $FL_t$: females | $L_\infty$=640.4; $K$=0.283; $t_0$=0 | 5.3.2.3 |
| | $FL_t$: males | $L_\infty$=612.8; $K$=0.327; $t_0$=0 | 5.3.2.3 |
| | $N_{sex,0}$ | 0.5 | 5.3.4. |
| | $Psexchange_t$ | 0 | 5.3.4. |
| | $t_{max}$ | 31.33 yr | 5.3.2 |
| *Spangled emperor* | *M* | 0.146 | Marriott *et al.* (2011a) |
| | $t_r$ | n/a: $t_{MLL}$used. | - |
| | MLL, $t_{MLL}$ | 41 cm *TL*, 3 yr | This section. |
| | $S_{sex,t}$ | $\begin{cases} 1....t > t_{MLL} \\ 0....t \le t_{MLL} \end{cases}$ | - |
| | $fec_t$ | $\overline{X}_{fec/g} * w_{female,t}$ | - |
| | $\overline{X}_{fec/g}$ | 41.2 eggs per gram | 5.2.4.3 |
| | $Pmat_t$ | $\dfrac{1}{1+e^{-1.375t+4.816}}$ | Marriott *et al.* (2010) |
| | $w_{sex,t}$ | $6.002*10^{-5}FL_t^{2.810}$ | Marriott *et al.* (2010) |
| | $FL_t$: females | North: $L_\infty$=591.5; $K$=0.254; $t_0$=-0.244 | Marriott *et al.* (2011a) |

| Species | Input | Equation / estimate | Source / Section |
|---|---|---|---|
| | | South: $L_\infty$ =623.7; $K$=0.177; $t_0$=-1.679 | Marriott *et al.* (2011a) |
| | $FL_t$: males | North: $L_\infty$ =556.3; $K$=0.318; $t_0$=0.064 | Marriott *et al.* (2011a) |
| | | South: $L_\infty$ =604.8; $K$=0.182; $t_0$=-1.612 | Marriott *et al.* (2011a) |
| | $N_{sex,0}$ | 1 | Marriott *et al.* (2010) |
| | $Psexchange_t$ | $\frac{0.5436}{1+e^{-3.786t+8.888}}$ | Marriott *et al.* (2010) |
| | $t_{max}$ | 30.75 yr | Marriott *et al.* (2010) |

### 6.3.3 Results

### 6.3.3.1 Pink snapper

#### 6.3.3.1.1 Oceanic stock

The assessment model indicated that female spawning biomass has been rebuilding since 2004 when the TACC was reduced by 40%. The model estimated that the rebuilding will continue and that the female spawning biomass will reach the management Target (40% of the 1952 level) by around 2014, if catches are maintained at or below the level in 2007/08 (i.e. ca 300 tonnes) (Fig. 6.3.1). The model estimated that the female spawning biomass was above the management Threshold (30% of the 1952 level) in 2008 with a probability of 0.95. The model indicated that fishing mortality has fallen sharply since 2002/03; the median value (approximates the harvest rate) fell below the assumed level of natural mortality (i.e. $M$ = 0.13) in 2008 (Fig. 6.3.1).

The most appropriate method of determining catch rates for the oceanic stock based on commercial (monthly) catch and effort data was fully discussed as part of the 2006 independent review (see 6.2). Catch rates estimated by the model generally fitted the observed catch rates estimated using the ‘Moran method’ (see 6.2 for more details). Observed catch rates showed an overall decline between 1992 and 2002 after which they levelled off before increasing from 2004 onwards (Fig. 6.3.2). The model, which takes into account the observed catch rates as well as the age-composition data, indicated a steady increase in catch rates after 2003 that was taken as an indication of increasing biomass.

The age composition predicted by the model generally fitted the observed data in all years (Fig. 6.3.3). The model indicated significant recruitment variation (as measured by numbers of 1+, i.e. fish in their second year of life) since the early 1990s; constant recruitment indicated by the model prior to 1992 is due to no information prior to the first year of catch-at-age data. Model estimates suggest that the oceanic stock has only had one very strong recruitment year since the early 1990s (in 1992) with some lower level recruitment in 2002 and 2006 (Fig. 6.3.4).

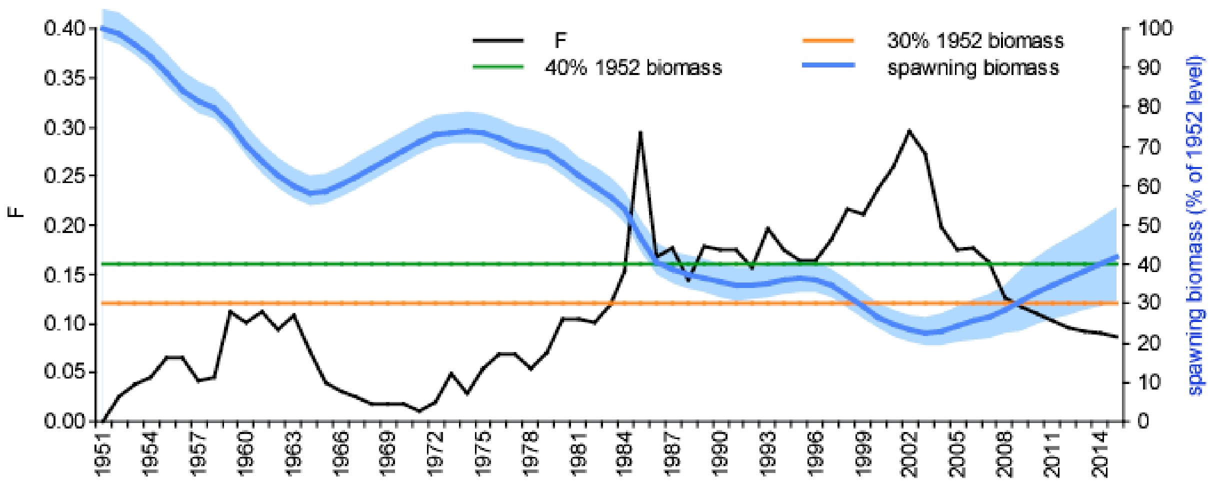



**Figure 6.3.1.** Female spawning biomass of the oceanic pink snapper stock as a percentage of the 1952 level (with 95% confidence intervals) and fishing mortality (F) when the total catch after 2008 is 303 tonnes. The biological reference levels of 30% and 40% of the 1952 female spawning biomass are shown. Fishing years have been abbreviated such that '1951' refers to 1951/52, '1954' to 1954/55 and so on.

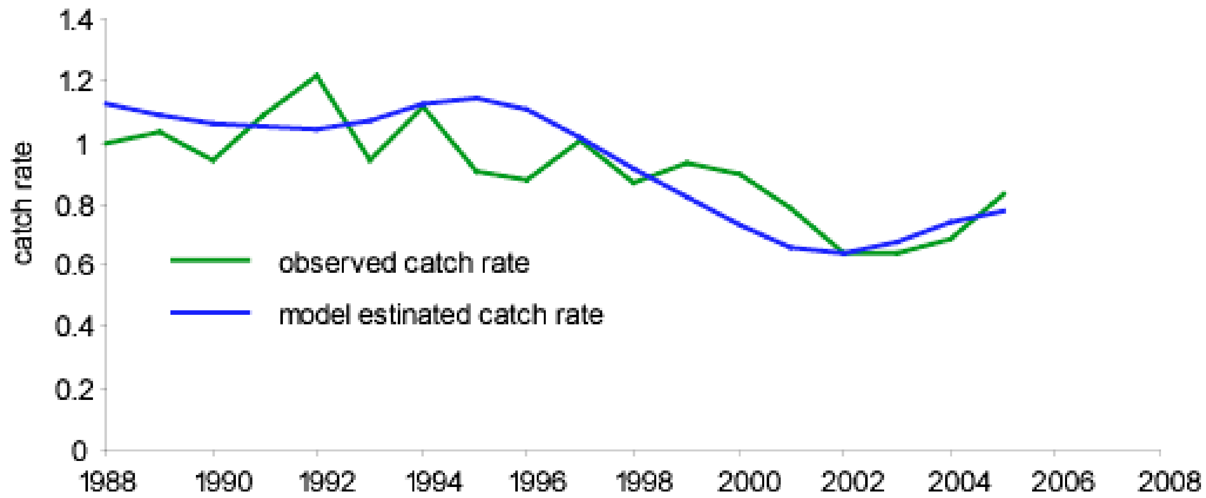



**Figure 6.3.2.** Catch rates for commercial catches taken by SBSF vessels 1989-2008 as determined by the 'Moran method' (see 6.2 for details). Fishing years have been abbreviated (see comment for Fig. 6.3.1).

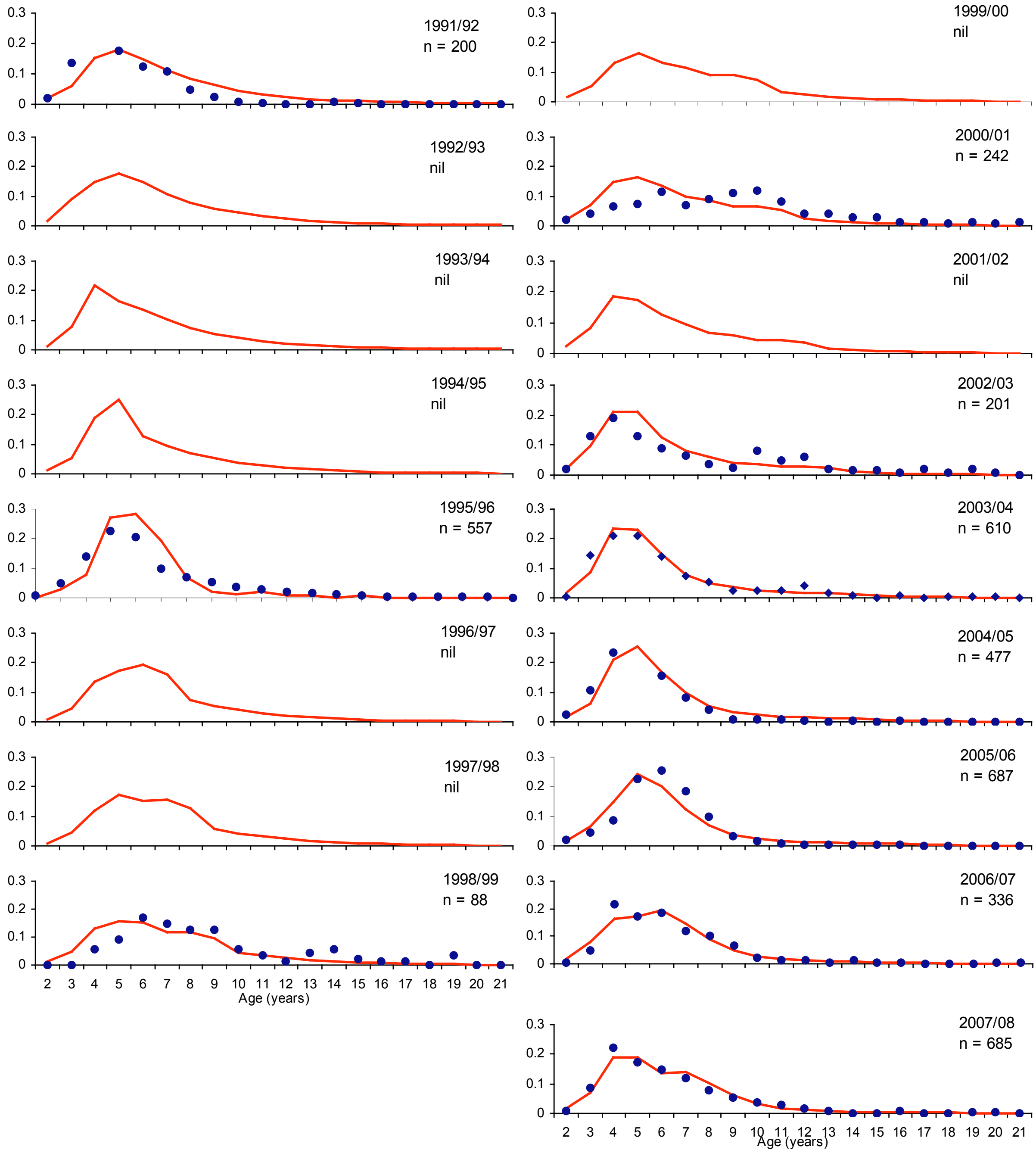



**Figure 6.3.3.** Age composition data for oceanic pink snapper stock 19991/92-2007/08 showing the observed age composition (blue dots) compared with the model estimated age-composition (orange lines). Sample sizes in each year as shown (no samples aged in 1992/93-1994/95, 1996/97-1997/98 and 1999/00).

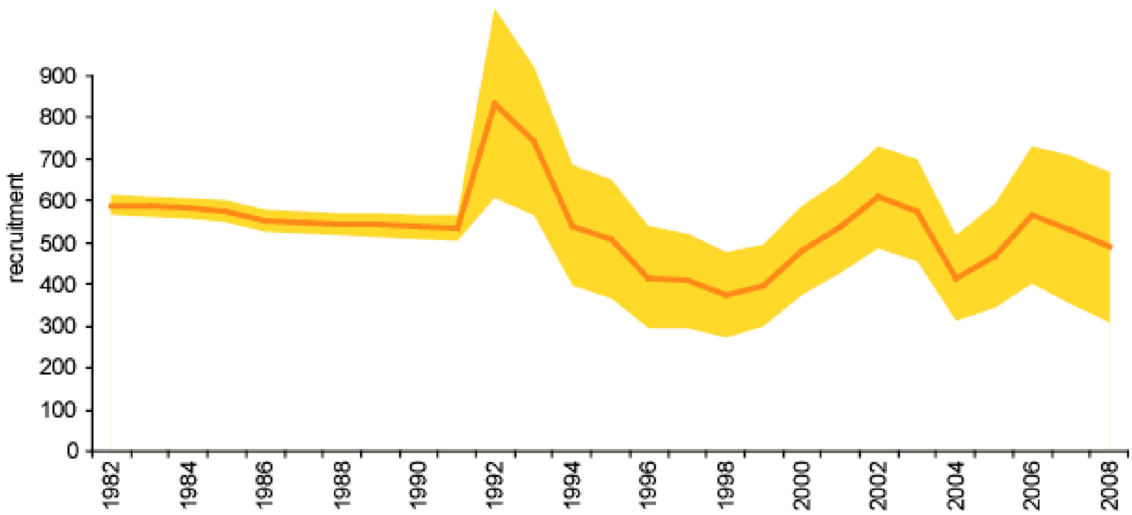



**Figure 6.3.4.** Recruitment variation (numbers of 1+, with 95% confidence intervals) in the oceanic pink snapper stock as estimated by the model. Note: that the model estimated a constant level of recruitment in period 1982-1990 is due to lack of age composition data for that period. Fishing years have been abbreviated (see comment for Fig. 6.3.1).

### 6.3.3.1.2 Inner gulf stocks

***Eastern Gulf***

The assessment model indicated that the mature biomass (males and females combined) fell below the management Target (40% of the unexploited level) around 1995 and to below the management Limit (20% of the unexploited level) around 1996 (Fig 6.3.5). Following the fishery closure (June 1998 to March 2003), the model indicated that the biomass started to rebuild from 1998-1999 onwards. The modelled age composition fitted the observed age composition data reasonably well (Fig. 6.3.6). The spawning biomass was estimated at approximately 45% of the unexploited level in 2008.

***Denham Sound***

The assessment model indicated that mature biomass fell below the management Target (40% of the unexploited level) in the early 1990s and to below the management Limit (20% of the unexploited level) around 1996-1998 (Fig 6.3.5). Since 1999 the mature biomass has been rebuilding. The modelled age composition fitted the observed age composition data reasonably well (Fig. 6.3.6). The mature biomass was estimated at approximately 42% of the unexploited level in 2008

***Freycinet Estuary***

The assessment model indicated that mature biomass declined to below the management Target (40% of the unexploited level) around 1997 and continued to decline to just below the management limit (20% of the unexploited level) around 2003, when a very conservative TAC (5 tonnes) and management quota-tags (see 3.2) were introduced (Fig 6.3.5). The modelled age composition fitted the observed age composition data reasonably well (Fig. 6.3.6). The model estimated age-composition indicated strong recruitment of 0-year-old snapper in 1990, 1993, 1996/97 and 2000 but no significant recruitment since 2000. The median mature biomass was at approximately 25% of the unexploited level in 2008. The mature biomass is rebuilding in response to the low catches since 2003. The model indicates that with a future catch of 5 tonnes per year, the median mature biomass is expected to be above the Target level by 2012 with a probability of 0.8.

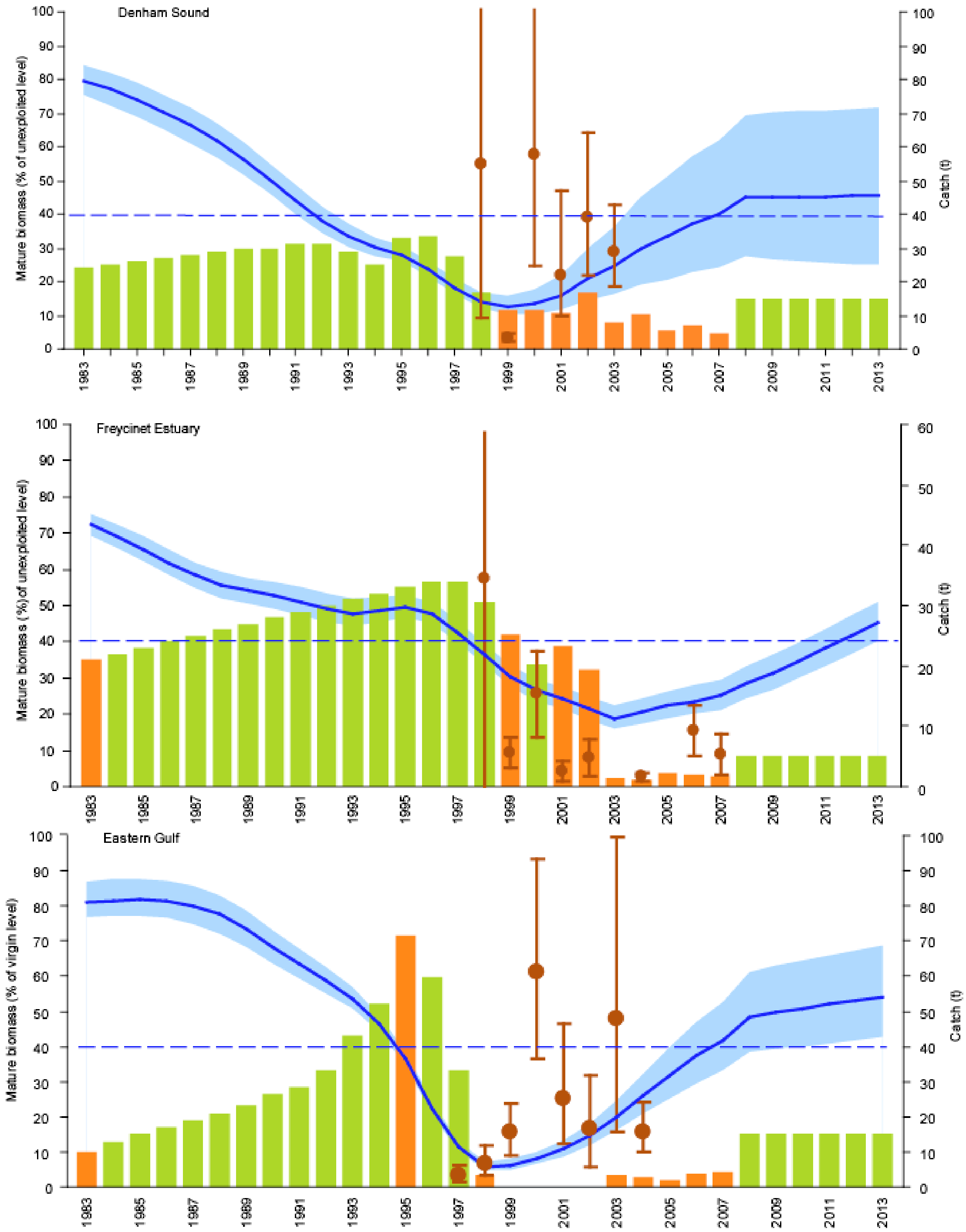



**Figure 6.3.5.** Model-based estimates of mature biomass of inner gulf snapper stocks (blue line) with 90% confidence intervals (blue shaded) relative to 40% of the unexploited level (hatched blue line). Fishery-independent estimates of stock size are from daily egg production method surveys (brown dots, error bars are ±1 SD). Survey-based estimates of recreational catch (orange bars) are distinguished from other years where catch levels were assumed (green bars).

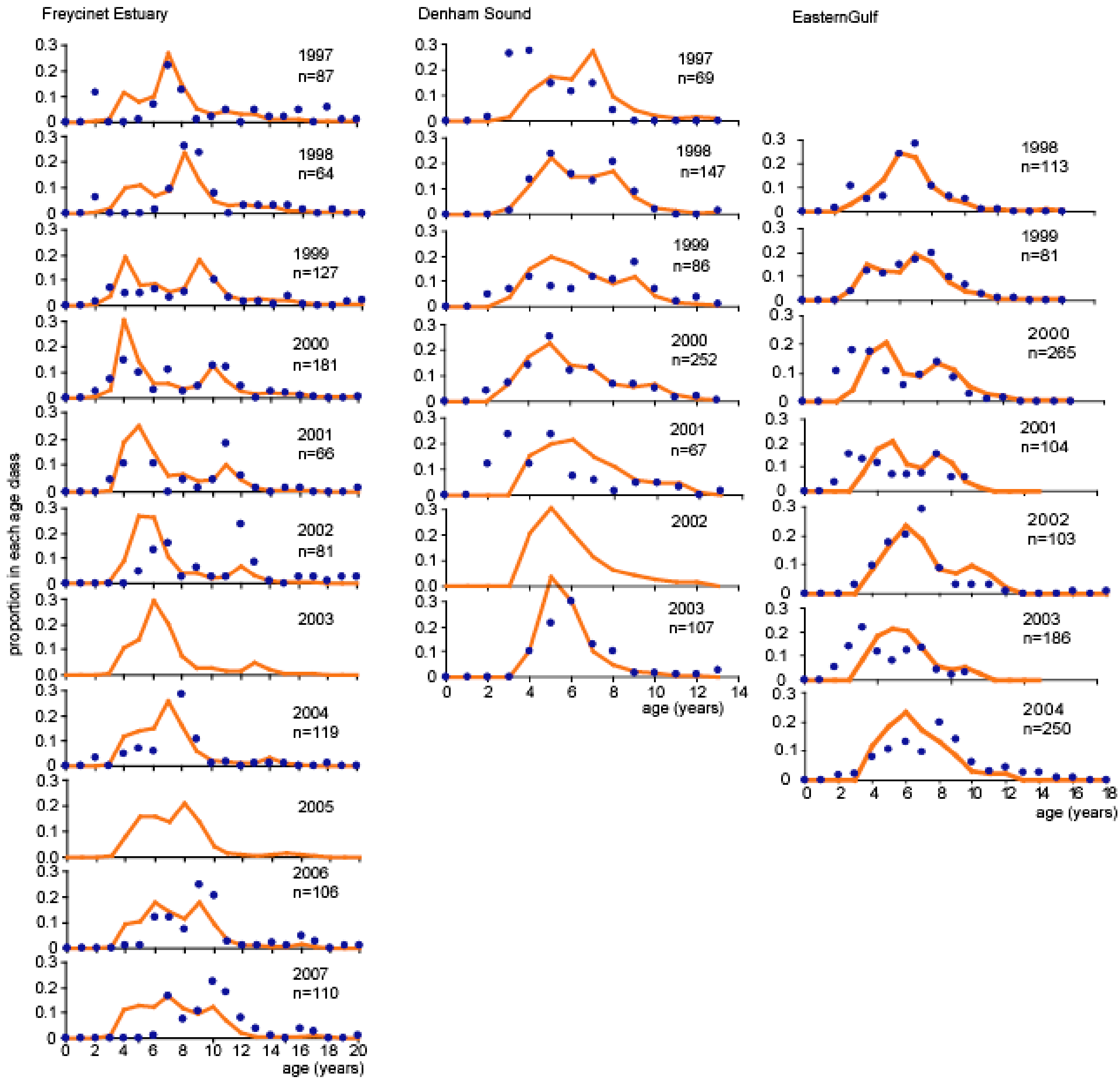



**Figure 6.3.6.** Age composition data for three inner gulf pink snapper stocks showing the observed age composition (blue dots) compared with model-predicted age-composition (orange lines). Samples sizes (number of fish aged in each year) are shown with the sample year.

**Table 6.3.11.** Summary of status of pink snapper stocks in 2008.

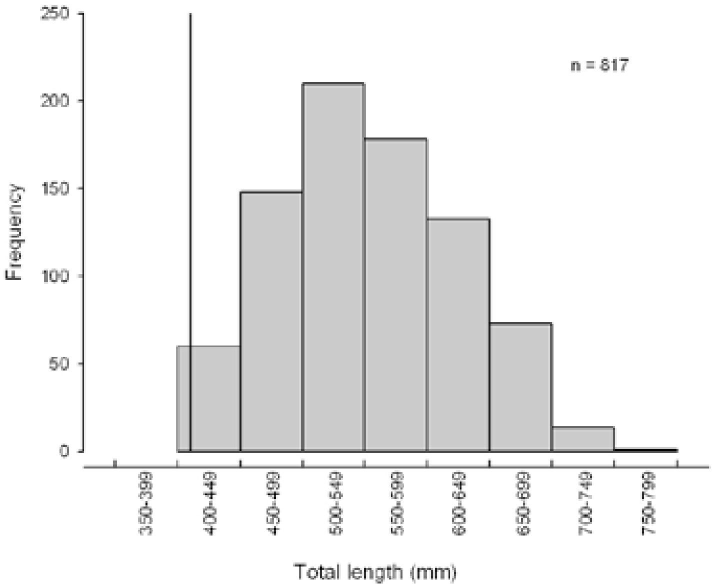
| Stock | | Spawning Biomass[1] | Reference level |
|---|---|---|---|
| Oceanic stock | Upper | 34.7 | |
| | Estimate | 28.3 | $B_{Threshold}>B>B_{Limit}$ |
| | Lower | 22.6 | |
| Eastern Gulf | Upper | 53.2 | |
| | Estimate | 48.5 | $B> B_{target}$ |
| | Lower | 44.1 | |
| Denham Sound | Upper | 69.4 | |
| | Estimate | 45.2 | $B> B_{target}$ |
| | Lower | 27.6 | |
| Freycinet Estuary | Upper | 33.2 | |
| | Estimate | 28.4 | $B_{Threshold}>B>B_{Limit}$ |
| | Lower | 24.1 | |

[1] Values presented as percentages of the estimated virgin (unfished) biomass of mature females for oceanic stock and biomass of all mature fish for inner gulf stocks.

### 6.3.3.2 Spangled emperor

#### 6.3.3.2.1 Catch size structure and selectivity

Catch at length distributions for spangled emperor demonstrated some similarities and differences between length distributions of spangled emperor retained by recreational and charter sectors within study regions (Fig. 6.3.7, 6.3.8). The modal length of spangled emperor landed by charter fishers was the same, and overall shape of the catch-at-length distribution similar as that landed by recreational fishers in the North Gascoyne (Zones 5-7; Fig. 6.3.7). These length distributions were not significantly different at the 5% significance level although there was nontrivial variation detected between them (25% significance level; Kolmogorov-Smirnov test: $n_1$=817, $n_2$=324, $d_{max}$=0.088, $D$=0.067, 0.05<$P$<0.25).





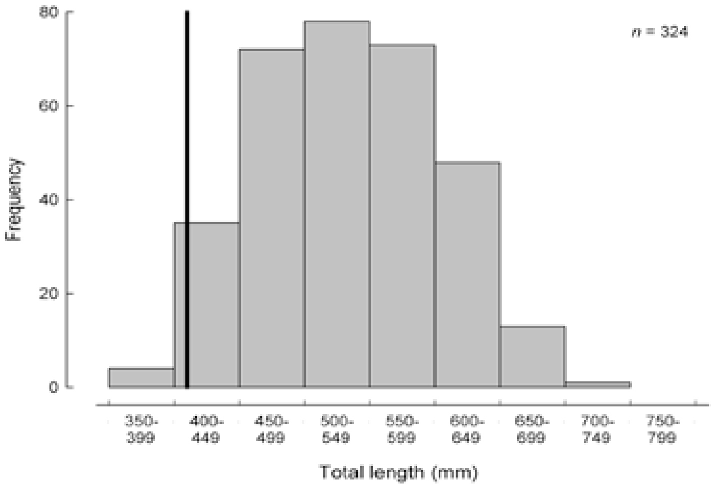
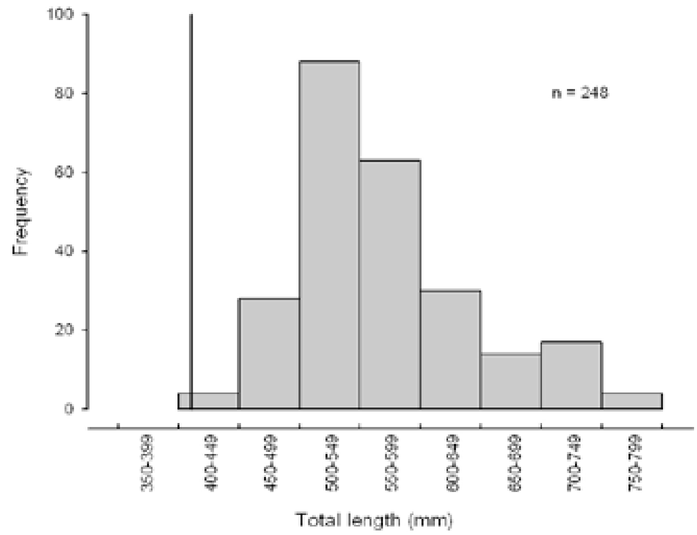




**Fig 6.3.7.** Length distributions of the retained catch of spangled emperor, North Gascoyne (Zones 5-7). Vertical line = MLL (410 mm *TL*).

The modal length of spangled emperor landed by charter fishers was smaller than that landed by recreational fishers in the South Gascoyne (Zones 2-4) and these length distributions were significantly different from one another (Kolmogorov-Smirnov test: $n_1$=248, $n_2$=232, $d_{max}$=0.138, $D$=0.124, $P$<0.05). A greater proportion of spangled emperor that were both smaller and larger than the size range of 500-600 mm TL were landed by recreational fishers than by charter fishers in zones 2-4 in 2007/08, reflecting a flatter (more platykurtic) recreational length distribution (Fig. 6.3.8). This suggests that charter fishers generally catch and retain a much narrower size range of spangled emperor than recreational fishers in the South Gascoyne. A representative catch at length distribution of spangled emperor from the commercial sector was not available for 2006/07 for comparison. These results show that the fishing mortality from recreational and charter fishers occurred across a similar size distribution of spangled emperor in each of the study regions, except for a narrower, and slightly smaller size range of spangled emperor caught by charter fishers in the South Gascoyne.

*Spangled emperor Zones 2-4, Charter (07/08)*




*Spangled emperor Zones 2-4, Recreational (07/08)*

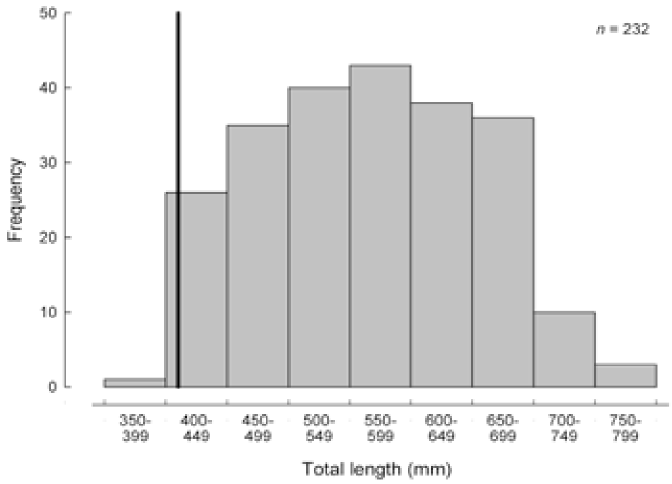



**Fig 6.3.8.** Length distributions of the retained catch of spangled emperor, South Gascoyne (Zones 2-4). Vertical line = MLL (410 mm *TL*). Data for zone 1 (i.e., Charter lengths, n=13) excluded.

The fit of the selectivity curve to selectivity coefficients calculated for age classes up to and including the modal age demonstrates that the age at full recruitment to the recreational fishery is relatively young, at 2 years old (290 mm *TL*) (Fig. 6.3.9). This likely reflects that recreational fishers often catch spangled emperor in areas where juveniles reside, and that fishing gear used by recreational fishers can catch juveniles.

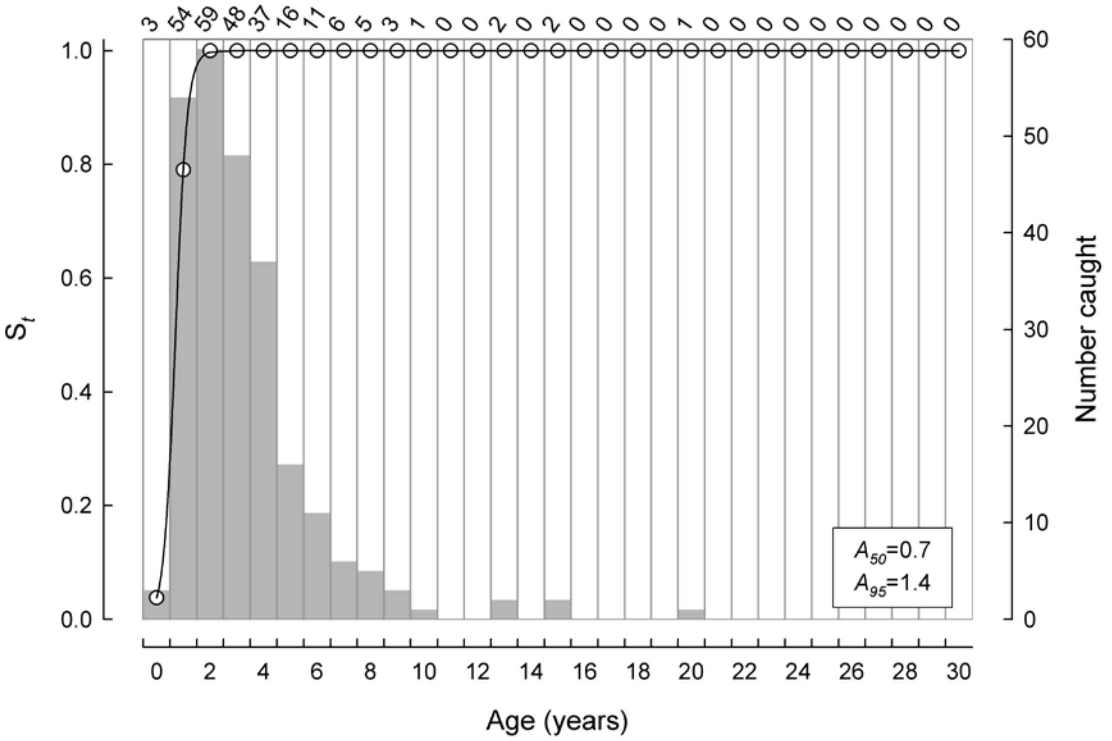



**Figure 6.3.9.** Selectivity curve for spangled emperor caught by recreational fishers. Open circles represent calculated selectivity coefficients, $S_t$ and fitted curve demonstrates line fishing selectivity for this species. Numbers represent the number of fish per derived catch at age data group ($\hat{t}$: yr) from RAP logbooks. $A_{50}$, $A_{95}$ = age(yr) at 50% and 95% full selectivity, respectively.

#### 6.3.3.2.2 Catch curve analysis

Estimates of *Z* from the fit of the different catch curve models were similar when fitted to each data group (i.e., representative catch-at-age distributions for boat-based recreational fishing shown in Fig. 5.2.4: North Gascoyne, South Gascoyne), but varied among models fitted to different data groups (Fig. 6.3.10, Table 6.3.12).

Wise *et al.* (2007) and Marriott *et al.* (2011a) showed that the use of alternative catch curve models was useful for demonstrating the effect of model selection uncertainty on results and tradeoffs of the alternative catch curve models used. Model I seemed to produce higher estimates of *Z* than the other methods because it was not fitted to data sampled for age classes older than a sample frequency of zero. Model II seemed to produce the best model fits in general, in terms of the evenness of residual distributions and the relatively wide ranges of age data that were fitted, although a bootstrapping analysis by Marriott *et al.* (2011a) demonstrated a propensity for the likelihood function to converge on relatively narrow ranges of multiple optima for *Z.* They explained this likely reflected the strong influence of changing values for the median and maximum ages fitted on the likelihood as a consequence of the step-wise model fitting algorithm (i.e., “stickiness”; Marriott *et al.* 2011a). Although Model III was fitted to a wider range of sampled age data, uneven distributions of residuals and heteroscedastic variation in the form of larger residuals near the modal age was likely to have exerted a high leverage on fits because it was fitted to the untransformed catch at age frequencies (Marriott *et al*. 2011a). In general, though, it was found that the different models produced similar results with respect to the pre-determined target levels for management; thus improving the confidence of results and robustness of subsequent advice to management. The observed differences in *Z* estimates produced by the different models generally reflected variability among the datasets and differences in model structure and model fitting algorithms among the methods.

The South Gascoyne 2007/08 dataset produced consistently lower estimates of *Z* compared to the North Gascoyne 2007/08 dataset. According to the values of *F* calculated from the catch curve estimates for *Z* and independent estimates of *M,* ratios of *F: M* for the South Gascoyne dataset were all below the Threshold level (i.e. $F<M$) (Fig. 6.3.10, Table 6.3.12). Ninety-five percent confidence intervals about the catch curve estimates (*Z*) demonstrated the range of uncertainty attributed to the fit of the catch curve models to observations. Importantly, the confidence intervals demonstrate uncertainty in the performance indicator with respect to reference levels for management, assuming *M* is known without error. This uncertainty ranged from between the Limit and Threshold levels to below the Target level for Method I, and consistently below the Target level for Methods II and III. This indicates a low probability of overfishing, given the data and assumptions of the analysis, at the 2007/08 levels of fishing for spangled emperor in the South Gascoyne.

In contrast, estimates of *F* for the North Gascoyne 2007/08 dataset were above the Limit reference level, except for the estimate from fitting of the Model III catch curve, which Marriott *et al*. (2011a) had shown produced a poor fit to older catch-at-age frequencies for this data set. This result indicated that the estimated *F* was high enough to be considered a risk to the sustainability of the North Gascoyne stock at the 2007/08 level of fishing effort and is evidence indicating localised overfishing. Note, however, that the *F* estimates only marginally exceeded the Limit level of 1.5*M*, at values of 1.56*M* and 1.70*M* (Table 6.3.12).

The 95% confidence intervals about the catch curve estimates (*Z*) demonstrate uncertainty in the performance indicator with respect to reference levels for management, assuming *M* is known without error. This uncertainty ranged from above the Limit level to between the Limit and Threshold levels for Methods I and II, and from above the Limit level to between the Threshold and Target levels for Method III. This indicates a medium to high probability of localised overfishing, given the data and assumptions of this analysis, at the 2007/08 level of fishing in the North Gascoyne.

Additionally, bias-adjusted 95% confidence intervals about the point estimates of *Z* and *M* showed: (i) in isolation, the quantified uncertainty about each estimate; and (ii) in combination, the quantified uncertainty in *F*, which was calculated by subtracting *M* from *Z* (Table 6.3.12). Estimates of bias-adjusted 95% confidence intervals around *M* from the bootstrapping method are wide and include biologically implausible values (Marriott *et al.* 2011a). Therefore, there is currently no plausible basis for estimating the 95% confidence intervals about *F* for these spangled emperor stocks. Work is currently underway to revise methods for obtaining uncertainty bounds around *M* and *F.*

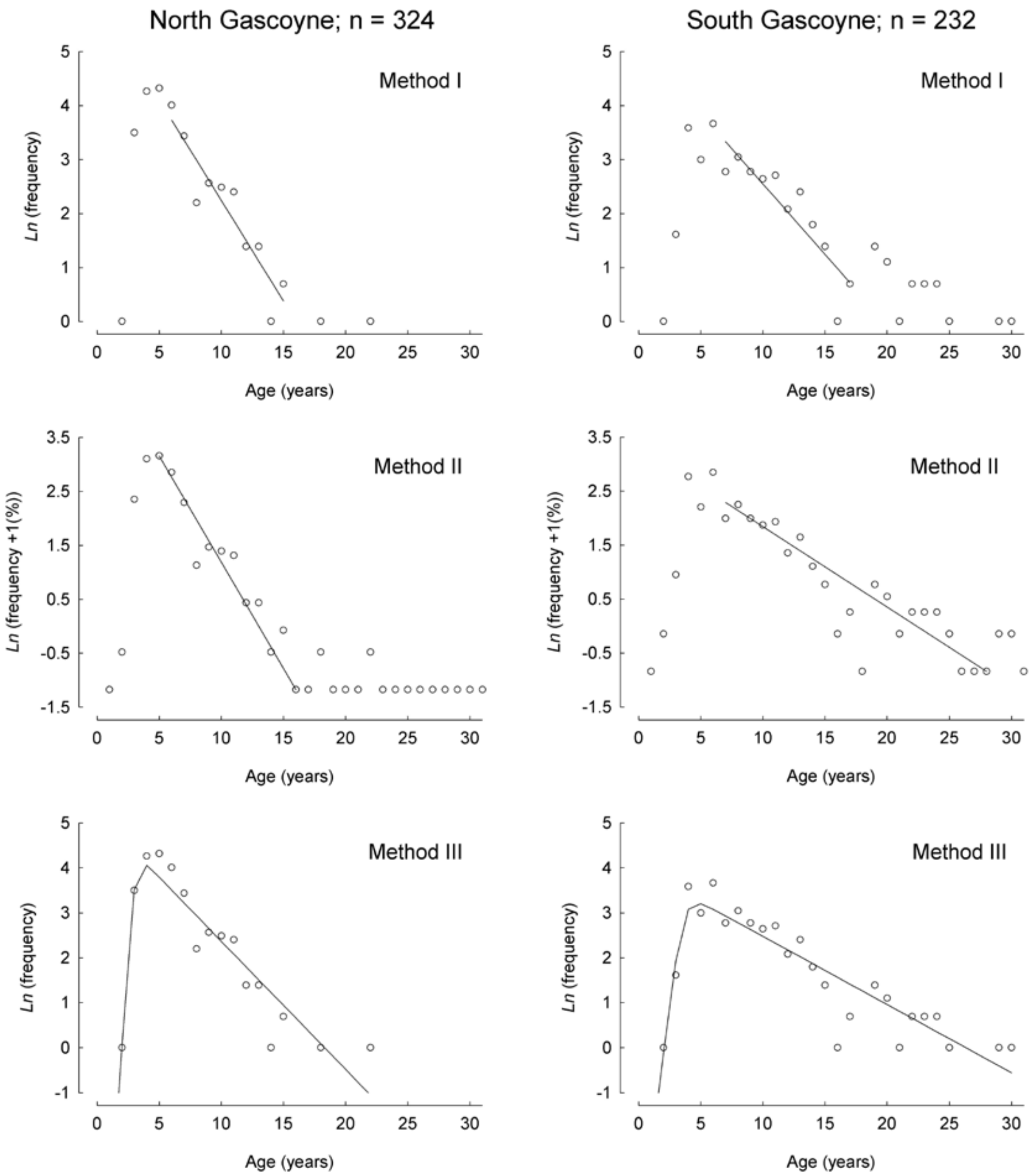



**Figure 6.3.10.** Fit of catch curves to Ln-transformed catch-at-age data for spangled emperor for each study region and method (Reproduced from Marriott *et al.* 2011a).

**Table 6.3.12.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the spangled emperor stocks. 'Upper' and 'Lower' refer to upper and lower bounds of bias-adjusted 95% confidence intervals. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise et al., 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Reproduced from Marriott *et al*. (2011a). Refer to Appendix 3 for results for different data groupings (commercial, calendar years). Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level.

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **North Gascoyne; n = 324** | | | | | |
| Method I | | | | | |
| Upper | 0.497 | 0.351 | | | |
| Estimate | 0.373 | 0.146 | 0.227 | 1.555 | $F_{Limit}$ < ***F*** |
| Lower | 0.294 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.500 | 0.351 | | | |
| Estimate | 0.394 | 0.146 | 0.248 | 1.697 | $F_{Limit}$ < ***F*** |
| Lower | 0.352 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.427 | 0.351 | | | |
| Estimate | 0.285 | 0.146 | 0.139 | 0.951 | $F_{Target}$ < ***F*** < $F_{Threshold}$ |
| Lower | 0.232 | 0.023 | | | |
| **South Gascoyne; n = 232** | | | | | |
| Method I | | | | | |
| Upper | 0.370 | 0.351 | | | |
| Estimate | 0.261 | 0.146 | 0.115 | 0.790 | $F_{Target}$ < ***F*** < $F_{Threshold}$ |
| Lower | 0.210 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.164 | 0.351 | | | |
| Estimate | 0.149 | 0.146 | 0.003 | 0.021 | ***F*** < $F_{Target}$ |
| Lower | 0.106 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.209 | 0.351 | | | |
| Estimate | 0.152 | 0.146 | 0.006 | 0.039 | ***F*** < $F_{Target}$ |
| Lower | 0.149 | 0.023 | | | |

Repetition of this analysis for datasets grouped by different types of year (i.e., calendar, commercial year groupings; Fig. 4.1) revealed that these results were relatively robust to decisions made concerning monthly samples to include or exclude based on year type (see Appendix 3). Estimates of *Z* were not significantly different between analyses for different year groupings, as determined from the overlap of bias-adjusted 95% confidence intervals, except for the fit of Method III catch curve to South Gascoyne data. In this instance, very narrow 95% confidence intervals (and lack of overlap between analyses) reflected that the Model III catch curve fitted relatively close estimates of *Z* despite introduced stochasticity that mimicked variability inherent in the observed data sets. However, although there was no overlap between *Z* estimates produced from the fit of Model III to recreational (Table 6.3.12) versus commercial year (Table A2) groupings of South Gascoyne data, the Reference level result was consistent between analyses.

**Table 6.3.13.** Comparisons of Reference levels derived from point estimates of $Z$ from catch curves fitted to data grouped by different year types. "Same" = same reference level as calculated for Recreational year (= Assessment year; Table 6.3.12); ** = Significant difference between $Z$ estimates as indicated by lack of overlap between 95% confidence intervals. All other results are not significantly different. See Appendix 3 for further details.

| | Recreational year | Calendar year | Commercial year |
|---|---|---|---|
| North Gascoyne | 1 Apr 07 – 31 Mar 08 | 1 Jan – 31 Dec 07 | 1 Sep 06 - 31 Aug 07 |
| Method I | $F_{Limit} < \boldsymbol{F}$ | Same | Same |
| Method II | $F_{Limit} < \boldsymbol{F}$ | $F_{Threshold} < \boldsymbol{F} < F_{Limit}$ | $F_{Threshold} < \boldsymbol{F} < F_{Limit}$ |
| Method III | $F_{Target} < \boldsymbol{F} < F_{Threshold}$ | Same | Same |
| South Gascoyne | | | |
| Method I | $F_{Target} < \boldsymbol{F} < F_{Threshold}$ | $\boldsymbol{F} < F_{Target}$ | Same |
| Method II | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| Method III | $\boldsymbol{F} < F_{Target}$** | Same | Same** |

Point estimates of $Z$ (and $F$) from the fit of each catch curve to the different data groupings did result in some important further insights into quantified levels of uncertainty, however. That the Method II estimates from analyses of both Calendar and Commercial year groupings indicated $F$ was between the Threshold and Limit levels for North Gascoyne data was further evidence of uncertainty in the result that $F$ exceeded the Limit level in the former analysis. The upper bounds of 95% confidence intervals of catch curve estimates in that second analysis consistently exceeded the Limit reference level and the lower bounds ranged from below the Target level to between the Limit and Threshold levels (Appendix 3: Tables A2, A3).

A previous study that was conducted by the DoFWA in the late 1980s and early 1990s estimated that the level of fishing mortality in the fished spangled emperor population off the North West Cape (within the North Gascoyne) was 1.1$M$ (Moran *et al.* 1993). Using a revised estimate of $M$ and the range of catch curve models presented in this report, the estimated fishing mortality from catch curve analyses for that early period (1989-91) ranged from 1.1$M$ to 1.3$M$, which was less than the $F_{Limit}$ level but higher than the $F_{Threshold}$ level (Marriott *et al.* 2011a). That an apparent effect of overfishing was also detected on the North Gascoyne age structure in 1989-91 suggests that fishing mortality on spangled emperor in that area was relatively high in the past (see also trends in historical levels of spangled emperor commercial catch (Section 6.1) and catch rates (Section 6.2) for Zones 5, 6 and 7). These inferences, however, are based on the key assumption that differences in observed age structures between North and South Gascoyne reflect differences in the level of fishing mortality between these regions (Marriott *et al.* 2011a).

#### 6.3.3.2.3 Per-recruit analysis

Trends for yield per recruit (YPR) and egg per recruit (EPR) were very similar for spangled emperor sampled from the North Gascoyne and South Gascoyne study regions, demonstrating the negligible influence of different growth estimates on model outputs for the different study regions (Fig. 6.3.11). $F$ at the maximum YPR was 0.46 (770 g recruit$^{-1}$) for North Gascoyne and 0.51 (665 g recruit$^{-1}$) for South Gascoyne, and the yield per recruit for the $F_{Limit}$ level of 1.5$M$ was 93.7% and 93.4% of the $F$ at maximum YPR for North Gascoyne and South Gascoyne, respectively. Therefore, for spangled emperor growth over-fishing is not predicted at the $F_{Limit}$

level, given the assumptions of the YPR model. At the $F_{\text{Limit}}$ level, EPR was predicted to reduce to 85.7% and 87.1% of the virgin EPR for North Gascoyne and South Gascoyne, respectively.

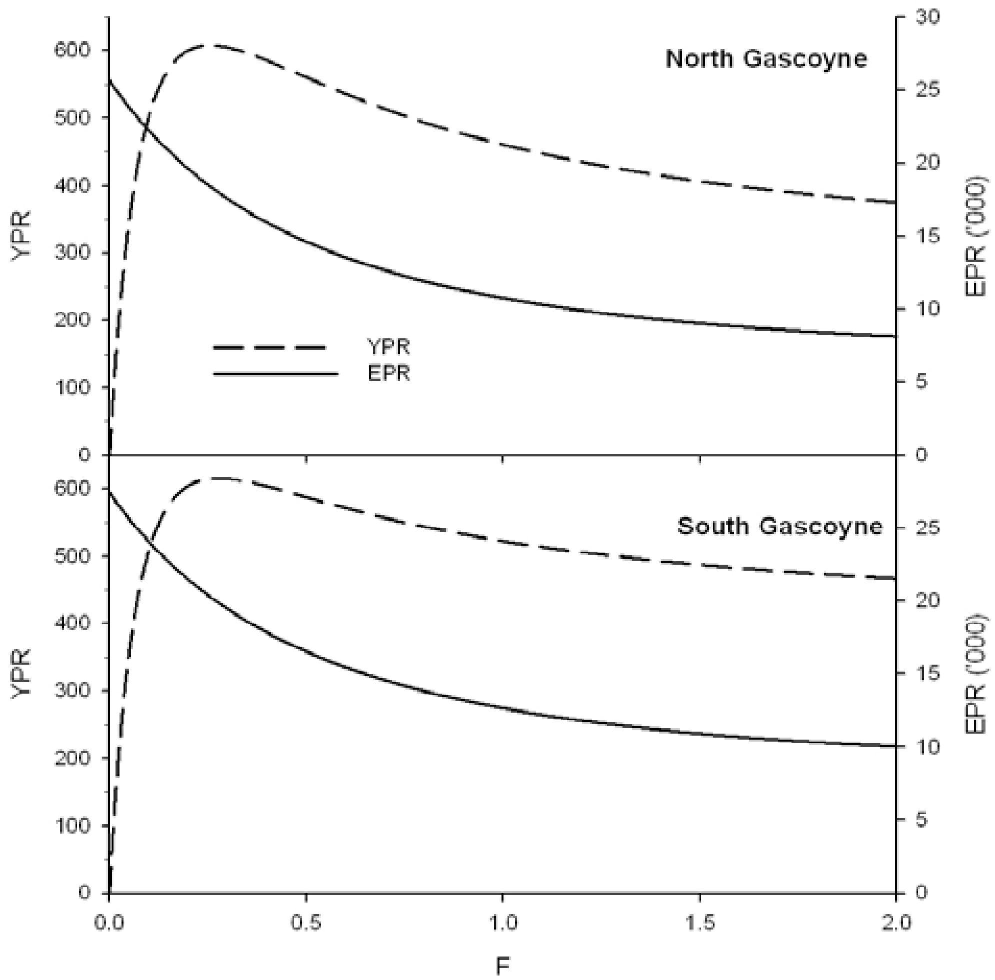



**Figure 6.3.11.** Yield per recruit (YPR in g/recruit) and eggs per recruit (EPR in eggs/recruit) with fishing mortality ($F$ year$^{-1}$) for spangled emperor in the North Gascoyne (Zones 5-7) and South Gascoyne (Zones 1-4) regions.

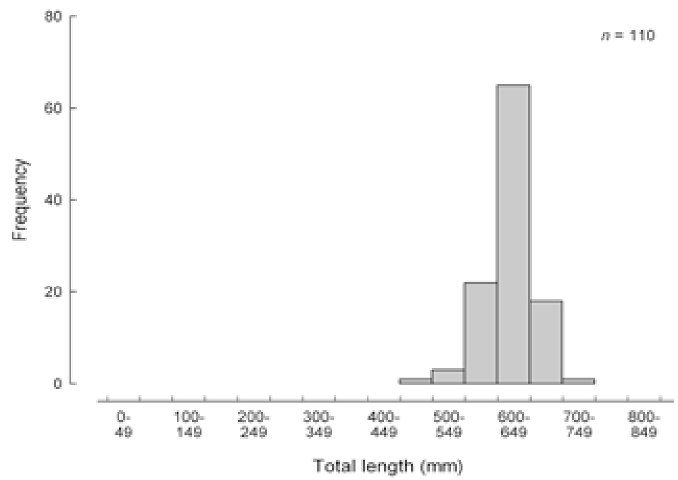
The per-recruit analyses suggest that although the estimated $F$ is above the $F_{\text{Limit}}$ level of 1.5$M$ this would not have a significant impact on yield- or egg production-per recruit in the North Gascoyne study region.

### 6.3.3.3 Goldband snapper

#### 6.3.3.3.1 Catch size structure and selectivity

Catch at length distributions for goldband snapper demonstrate that commercial fishers caught and retained a greater proportion of larger goldband than charter fishers (Fig. 6.3.12). It is possible that this might reflect differences in gear selectivity (e.g. hook sizes) and/or spatial distribution of effort between these sectors, if fish of different sizes occurred in different fishing grounds of the different sectors. It is also evident that the size ranges of goldband snapper landed by both sectors (mostly) exclude the catches of small (< 450 mm TL) fish.

*Goldband snapper Zones 2-4, Charter (07/08)*




*Goldband snapper Zones 2-4, Commercial (07/08)*

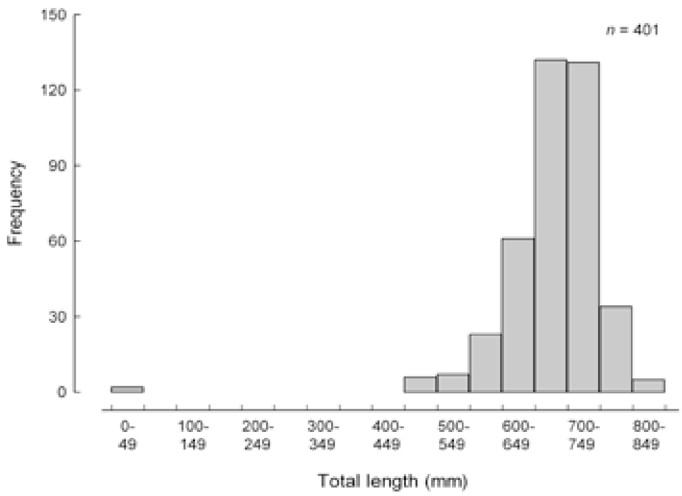



**Fig 6.3.12.** Length distributions of the retained catch of goldband snapper, Zones 2-4.

These results demonstrate that fishing by commercial fishers captured larger goldband snapper than fishing by charter fishers in the South Gascoyne for this assessment year. A representative recreational catch at length distribution of goldband snapper was not available for comparison for this assessment year.

The fit of the selectivity curve to selectivity coefficients calculated for age classes up to and including the modal age demonstrates that the age at full recruitment to the commercial fishery for goldband snapper is relatively old, at approximately 8 years (Fig 6.3.13). In the absence of a MLL for this species, this shows that the younger fish are either not selected by the commercial line fishing gear, or they are not available to capture in the grounds that are fished.

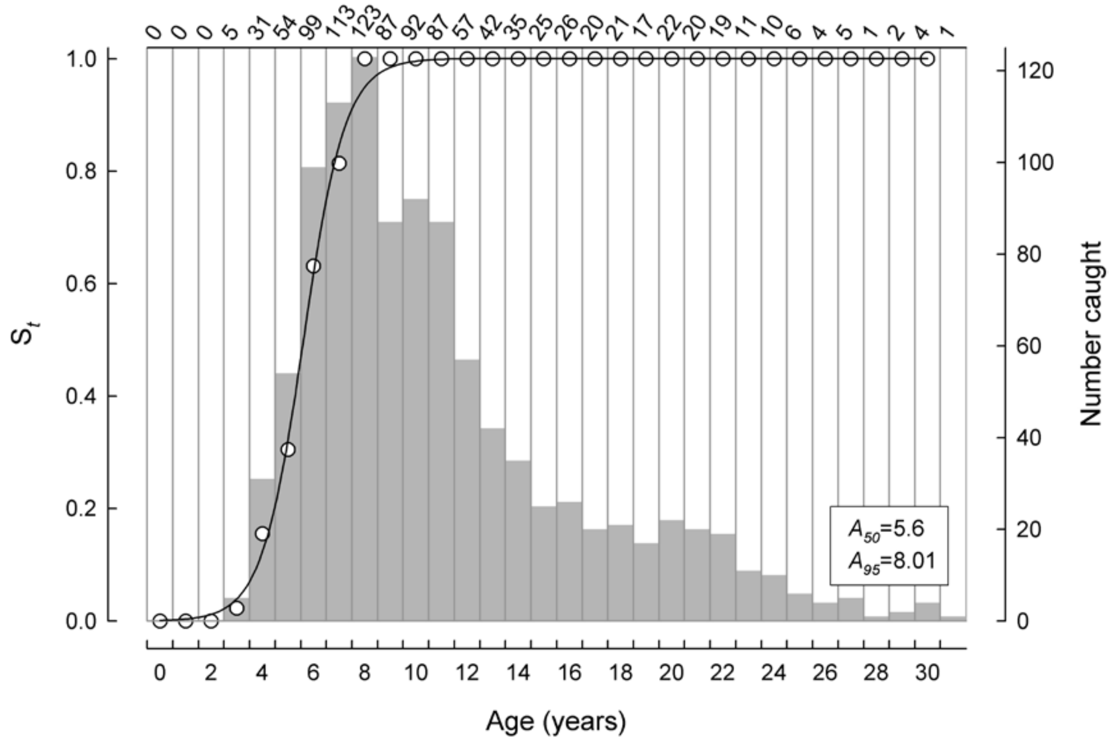



**Fig 6.3.13.** Selectivity/availability curve for goldband snapper caught by commercial fishers. Open circles represent calculated selectivity coefficients, $S_t$ and fitted curve the line fishing selectivity for this species. Numbers represent the number of fish per catch at age data group (yr) from biological samples collected from the landed catches of commercial fishers, pooled across years (2004-2008). $A_{50}$, $A_{95}$ = age (yr) at 50% and 95% full selectivity, respectively.

#### 6.3.3.3.2 Catch curve analysis

The three different catch curve models demonstrated similar fits to the descending slopes of natural logarithm of (*Ln*)-transformed age-frequency data, past the observed modal age (Fig 6.3.14). Wise *et al.* (2007) and Marriott *et al.* (2011a) showed that the use of alternative catch curve models was useful for demonstrating the effect of model selection uncertainty on results and tradeoffs of the alternative catch curve models used. The observed differences in *Z* estimates produced by the different models generally reflected variability among the datasets and differences in model structure and model fitting algorithms among the methods, as explained for catch curve analyses of spangled emperor stocks in Section 6.3.3.2.2.

The fit of catch curve models to 2007/08 data, however, were steeper than to 2005/06 data (Fig 6.3.14). A high proportion of positive residuals was observed for the fit of the models to age classes 8 – 13 years of the 2005/06 data, which indicated that the catch curve models did not fit well to catch-at-age data for these age classes, but did fit well to age classes older than 13 years in commercial samples for that year (Fig 6.3.14). Conversely, an even dispersion of residuals, and lower residual variation, was observed for the fit of catch curve models to 2007/08 data, possibly reflecting the higher number of specimens analysed and therefore better sampling precision achieved for that commercial sampling year (Fig 6.3.14).

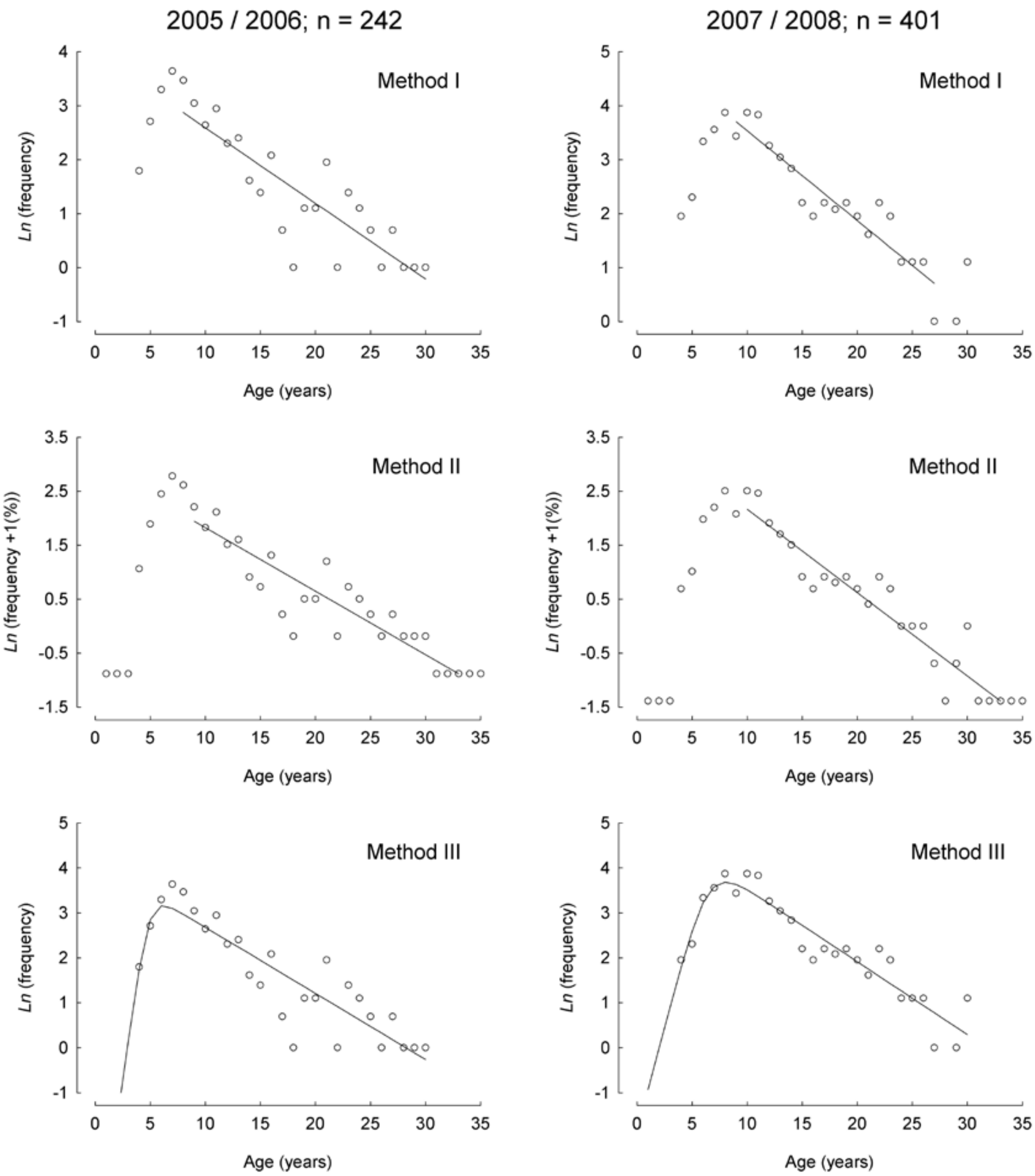



**Figure 6.3.14.** Fit of catch curves to Ln-transformed catch-at-age data for goldband snapper for each assessment year and catch curve model.

Estimates of *Z* (total mortality) from these different models were similar when fitted to each data group for each commercial sampling year, but varied between years, with consistently higher estimates for 2007/08 than for 2005/06 (Table 6.3.14). Estimates of *Z* were also less precise for 2005/06 data, as indicated by the larger bias-adjusted 95% confidence intervals about the point estimates of *Z,* than the 2007/08 estimates (Table 6.3.14). Point estimates of *F: M* were all below the Target level of $F = M$ except for the fit of Model II to 2005/06 data because a biologically realistic value of *F* could not be calculated (i.e., $Z < M$) (Table 6.3.14). That the *F* values were consistently below the $F_{\text{Target}}$ level for all methods and years indicates that there were no detectable effects of fishing on the population age structure of goldband snapper in the South Gascoyne for those assessment years.

Ninety-five percent confidence intervals about the catch curve estimates (*Z*) demonstrated the range of uncertainty attributed to the fit of the catch curve models to observations. Importantly, the confidence intervals demonstrate uncertainty in the performance indicator with respect to reference levels for management, assuming *M* is known without error. This uncertainty ranged from between the Threshold and Target levels to below the Target level for Method I and III estimates for 2005/06 data and for the Method III estimate for 2007/08 data, consistently below the Target level for Method II estimates, and from between the Limit and Threshold levels to below the Target level for the Method I estimate of 2007/08 data. This indicates a generally low probability of overfishing, given the data and assumptions of the analysis, at the 2005/06 and 2007/08 levels of fishing for goldband snapper in the South Gascoyne.

Additionally, bias-adjusted 95% confidence intervals about the point estimates of *Z* and *M* showed: (i) in isolation, the quantified uncertainty about each estimate; and (ii) in combination, the quantified uncertainty in *F*, which was calculated by subtracting *M* from *Z.* For goldband snapper, there is currently no estimate for the 95% confidence bounds around *M* so 95% confidence intervals for *F* could not be calculated. Work is currently underway to revise methods for obtaining uncertainty bounds around *M* and *F.*

Repetition of this analysis for datasets grouped by different types of year (i.e., calendar, recreational year groupings; Fig. 4.1) revealed that these results were robust to decisions made concerning which monthly samples to include or exclude based on year type (see Appendix 4). Estimates of *Z* were not significantly different between analyses for different year groupings, as determined from the overlap of bias-adjusted 95% confidence intervals. Comparisons of point estimates of *Z* (and *F*) from the fit of each catch curve to different data groupings is summarised in Table 6.3.15.

**Table 6.3.14.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the goldband snapper stock for each commercial fishing year analysed. 2006/07 data excluded due to low sample size. 'Upper', 'Lower' and 'Estimate' and refer to: (i) the upper and lower bounds of bias-adjusted 95% confidence intervals, and the deterministic estimate, for *Z*; and (ii) the upper end, lower end and median of the range estimated by Newman and Dunk (2003) for *M*. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise *et al.*, 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level. Refer to Appendix 4 for results for different data groupings (recreational, calendar years).

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **2005/06; n = 242** | | | | | |
| Method I | | | | | |
| Upper | 0.211 | 0.139 | | | |
| Estimate | 0.140 | 0.121 | 0.019 | 0.156 | ***F*** < $F_{Target}$ |
| Lower | 0.057 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.133 | 0.139 | | | |
| Estimate | 0.118 | 0.121 | -0.004 | n/a | ***F*** < $F_{Target}$ |
| Lower | 0.095 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.212 | 0.139 | | | |
| Estimate | 0.147 | 0.121 | 0.026 | 0.212 | ***F*** < $F_{Target}$ |
| Lower | 0.126 | 0.104 | | | |
| **2007/08; n = 401** | | | | | |
| Method I | | | | | |
| Upper | 0.247 | 0.139 | | | |
| Estimate | 0.167 | 0.121 | 0.045 | 0.373 | ***F*** < $F_{Target}$ |
| Lower | 0.137 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.160 | 0.139 | | | |
| Estimate | 0.155 | 0.121 | 0.033 | 0.274 | ***F*** < $F_{Target}$ |
| Lower | 0.143 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.202 | 0.139 | | | |
| Estimate | 0.162 | 0.121 | 0.041 | 0.337 | ***F*** < $F_{Target}$ |
| Lower | 0.140 | 0.104 | | | |

**Table 6.3.15.** Comparisons of Reference levels derived from point estimates of $Z$ from catch curves fitted to data grouped by different year types. Data for 2006, 2007 calendar years and for 2006/07 recreational years not included due to small sample sizes attained for those data groupings. "Same" = same reference level as calculated for Commercial year (= Assessment year; Table 6.3.14); 95% Confidence intervals overlapped for all results compared indicating that year type grouping had no significant influence. See Appendix 4 for further details.

| | Commercial year | Calendar year | Recreational year |
|---|---|---|---|
| 2005/06 | 1 Sep 05 – 31 Aug 06 | 1 Jan – 31 Dec 05 | 1 Apr 05 – 31 Mar 06 |
| Method I | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| Method II | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| Method III | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| 2007/08 | 1 Sep 07 – 31 Aug 08 | 1 Jan – 31 Dec 08 | 1 Apr 08 – 31 Mar 09 |
| Method I | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| Method II | $\boldsymbol{F} < F_{Target}$ | Same | Same |
| Method III | $\boldsymbol{F} < F_{Target}$ | Same | Same |

The upper bounds of 95% confidence intervals of catch curve estimates in this second analysis ranged from above the Limit reference level to below the Target level. Lower bounds were consistently below the Target reference level (Appendix 4: Tables A4, A5). This further indicates that, although some catch curve estimates were relatively imprecise, in general there is a low probability of localised overfishing of goldband snapper in the South Gascoyne given the data and assumptions of the analysis, at 2005/06 and 2007/08 levels of fishing for this species.

#### 6.3.3.3.3 Per-recruit analyses

The yield per recruit (YPR) and egg per recruit (EPR) trends for goldband snapper were quite different than those described for spangled emperor for the current pattern of commercial fishing selectivity (i.e. representing the majority of catches in the GCB; Section 6.1) (Fig. 6.3.15). For the current pattern of selectivity, $F$ at the maximum YPR was 0.67 (1,122 g recruit$^{-1}$) and the yield per recruit for the $F_{Limit}$ level of $1.5M$ was 83.8% of the $F$ at maximum YPR. Therefore, under the current pattern of fishing selectivity, growth over-fishing is not predicted at the $F_{Limit}$ level. If the selectivity pattern changes to catching older fish, however, growth overfishing at the $F_{Limit}$ level is expected, and if the selectivity pattern changes to catching younger fish, at the $F_{Limit}$ level, the YPR would also decrease from the maximum YPR (Figure 6.3.15).

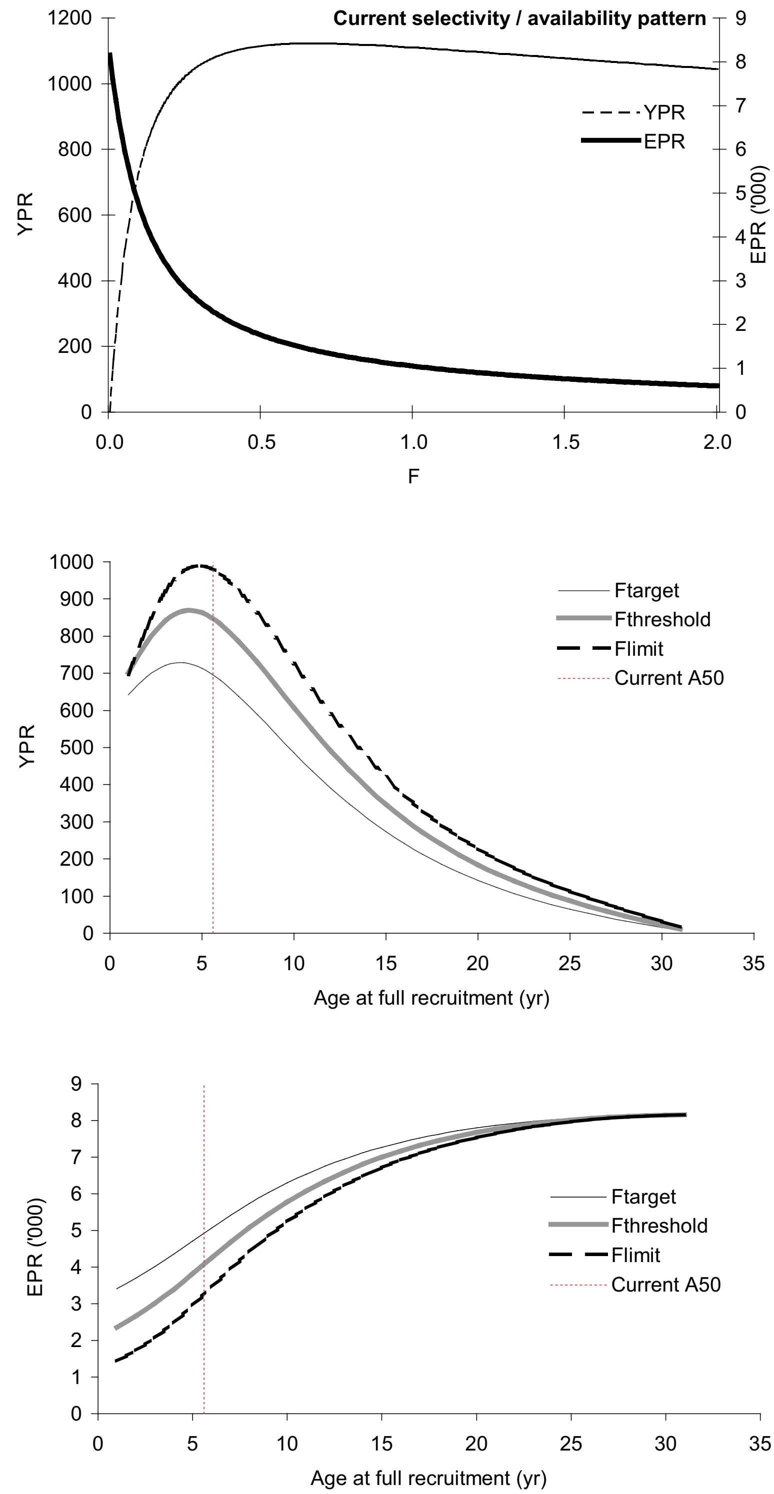



**Figure 6.3.15.** Yield per recruit (YPR in g recruit$^{-1}$) and eggs per recruit (EPR in g recruit$^{-1}$) with fishing mortality (*F* year$^{-1}$) for goldband snapper in the Gascoyne Coast Bioregion. Results shown for: under current selectivity described for the commercial sector (see Figure 6.3.13) (top); under hypothetical knife-edged selectivity for YPR (middle); and EPR (bottom), to show potential effects of a change in selectivity pattern. Vertical dashed red line shows the average age that goldband snapper are currently selected by the commercial sector (A50=5.6 yr from Fig. 6.3.13)

Under the current pattern of selectivity, the EPR was predicted to be reduced to 62.4%, 52.3% and 42.1% of the virgin EPR at the $F_{\text{Target}}$, $F_{\text{Threshold}}$ and $F_{\text{Limit}}$ levels, respectively, indicating a relatively high intrinsic vulnerability for recruitment overfishing of goldband snapper stocks (Table 6.3.16). Further, a drop in the average age from which goldband snapper are selected (i.e., caught by fishing) resulted in declines in the expected EPR, with greater declines under higher levels of *F* (Figure 6.3.15; Table 6.3.16). This indicates a high sensitivity of the Gascoyne goldband snapper stock to recruitment overfishing should the current pattern of selectivity change to catching smaller, younger fish.

**Table 6.3.16.** Egg per recruit (EPR) as a percentage of the virgin EPR with changing catch selectivity for goldband snapper. * = Calculated using the current observed selectivity pattern for the commercial sector (Figure 6.3.12). Otherwise, "age at selectivity" is a knife-edged function, occurring at the presented age for each row (see Methods, Section 6.3.2.2.1).

| Age at selectivity (yr) | $F_{target}$ | $F_{threshold}$ | $F_{limit}$ |
|---|---|---|---|
| 1 | 42% | 29% | 18% |
| 2 | 45% | 33% | 21% |
| 3 | 49% | 37% | 25% |
| 4 | 53% | 42% | 30% |
| 5 | 58% | 47% | 36% |
| Current (*A*50 = 5.6)* | 62% | 52% | 42% |
| 6 | 62% | 52% | 42% |
| 7 | 66% | 57% | 48% |
| 8 | 70% | 62% | 54% |
| 9 | 74% | 67% | 59% |
| 10 | 77% | 71% | 64% |

### 6.3.4 Summary of key findings

The different assessment approaches used for the three indicator species reflect varying levels of data availability that in turn reflect the different historic levels of investment in monitoring and assessment. The assessments for spangled emperor and goldband snapper, that were only possible due to recent research using the indicator species approach, have supplemented those for pink snapper stocks in the Bioregion, for which the Department had well-established research and monitoring programs at the time of this assessment.

Due to the limited data available, it was only possible to undertake simpler forms of assessment (i.e. fishing mortality) for spangled emperor and goldband stocks. These approaches produced results for these species that should be interpreted as having higher levels of unquantified uncertainty than those for pink snapper. Conclusions from these assessments are summarised for each stock as follows.

#### 6.3.4.1 Pink snapper

***Oceanic stock***

- Integrated age-structured assessments indicate that oceanic stock is recovering following a series of reductions in TACC since 2004.
- Moderate level of uncertainty remains around the assessments although data availability is reasonable, at least for commercial catches (represent ~80-90% of total catch overall).

***Inner gulf stocks***

- Integrated age-structure assessments indicate that Eastern Gulf and Denham Sound stocks are above management Target (40% of the unexploited level) while Freycinet Estuary stock is still rebuilding (projected to reach Target 40% level by 2012).
- Some level of uncertainty remains around the assessments due to inadequate information on historical catches (period 1960s-early 1990s).

#### 6.3.4.2 Spangled emperor

***North Gascoyne***

- Most of the commercial catch, during the peak period of commercial catches (late 1980s to mid-1990s), and most of the recreational (1998/99, 2007/08) and charter (2002/03-2007/08) catch of spangled emperor, was taken from the North Gascoyne. Landed catches from recreational and charter fishers in 2007 occurred across similar size distributions of spangled emperor. Data from voluntary angler logbooks showed that some recreational fishers caught and released a high proportion of juveniles below the MLL.
- A declining commercial catch rate, standardised for vessel and season, was observed from late 1980s to mid 1990s, which could reflect declining localised abundances of spangled emperor, known changes in commercial fishing, or other factors influencing CPUE.
- Catch-curve assessments indicate that localised overfishing was occurring in 2007/08, with estimates only marginally exceeding the Limit reference level. Several sources of quantified uncertainty suggested that the probability of localised overfishing occurring in 2007/08 was medium to high. Alternative methods indicated that $F$ was below the Limit level but above the Threshold level.
- The per-recruit analyses suggested that although the estimated $F$ is above the $F_{\text{Limit}}$ level of $1.5M$ this would not have a significant impact on yield- or egg production-per recruit.
- This assessment should be taken in context of the presented levels of uncertainty in $Z$ and $M$, that only fish sampled from catches made outside of sanctuary zones were analysed, analysis assumptions, trends in catches, effort, and the inherent biological vulnerability of this species (see Section 7).

***South Gascoyne***

- Catch-curve assessments indicate no evidence of overfishing and that the stock is currently fished at sustainable levels of catch in the South Gascoyne. Several sources of quantified uncertainty suggested that the probability of localised overfishing occurring in 2007/08 was low.
- The per-recruit analyses suggested that if $F$ increased to above the $F_{\text{Limit}}$ level this would not have a significant impact on yield- or egg production-per recruit.
- This assessment should be taken in context of the presented levels of uncertainty in $Z$ and $M$, analysis assumptions, trends in catches, effort, and the inherent biological vulnerability of this species (see Section 7).

#### 6.3.4.3 Goldband snapper

***South Gascoyne***

- The age at full recruitment to the commercial fishery is relatively old, at approximately 8 years of age, indicating that many younger fish are not currently susceptible to fishing mortality by the commercial sector.
- Fishing mortality by commercial fishers occurred for larger goldband snapper than fishing mortality by charter fishers in the South Gascoyne in 2007.
- Catch-curve assessments indicate no evidence of overfishing and that the stock is fished within the target range of catch in 2007/08. Several sources of quantified uncertainty suggested that the probability of localised overfishing occurring in 2005/06 and 2007/08 was low.
- The per-recruit analyses indicated a relatively high intrinsic vulnerability for goldband snapper stocks. Any increases in $F$ or a decrease in age at selectivity were estimated to have a relatively large impact on egg per recruit for the stock.
- This assessment should be taken in context of the presented levels of uncertainty in $Z$ and $M$, analysis assumptions, trends in catches, effort, and the inherent biological vulnerability of this species (see Section 7).

# 7.0 General discussion and implications

## 7.1 Introduction

The DoFWA currently employ 5 alternative levels of stock assessment methods (DoF 2011). The choice of assessment method depended on the amount and suitability of available data. The different levels of assessments completed for each of the indicator stocks produced different types and complexity of estimates for current stock status. Assessments of pink snapper stocks using integrated models (i.e., Level 5 assessment; DoF 2011) produced estimates of spawning stock biomass, fishing mortality, and forecasted trajectories of spawning stock biomass. Accordingly, model outputs were used to estimate sustainable catch levels for each stock, as determined with respect to standard reference levels ($B_{Target}$, $B_{Threshold}$, $B_{Limit}$, $F_{Target}$, $F_{Threshold}$, $F_{Limit}$) and in context of each fishery's respective harvest strategy or management review cycle.

In the case of Level 3 assessments (based on catch curve analysis, e.g. Wise *et al.* (2007) for spangled emperor and goldband snapper stocks, no specific estimates of sustainable catch levels are produced. Instead, the catch curve analyses are used to estimate the current level of fishing mortality on the age structures of the stocks (*F*), which is related to reference levels ($F_{Target}$, $F_{Threshold}$, $F_{Limit}$) and corresponding decision rules, as specified in Table 7.1 and Table 7.2. The decision rules outline a range of catch reductions that should be undertaken where unsustainable levels of fishing are identified. This is consistent with the 'weight-of-evidence' approach to assessments developed by the DoFWA (Wise *et al.* 2007). In cases where a reduction in catch and/or effort is required according to these decision rules, the level of reduction can be refined according to other attributes that affect sustainability risk (Wise *et al.* (2007), which has been recently demonstrated as a robust approach for data-limited multi-species demersal scalefish fisheries in Western Australia (Hall and Wise 2011).

**Table 7.1.** The suggested management actions resulting from an initial assessment of indicator levels of biomass and fishing pressure (from Wise et al. 2007). Note: if current monitoring and management is already in place to address previously identified sustainability risk(s), it may not be necessary to impose further "restrictions" on fishing on the basis of the level of biomass or fishing mortality estimated for any one year. For instance, the detection of trends in or the trajectories of performance indicators may be more relevant to achieving sustainability objectives for a fishery that is in a stock rebuilding phase.

| | | **Fishing Mortality (F)[1]** | | | |
|---|---|---|---|---|---|
| | | **$F<F_{target}$** | **$F_{target}<F<F_{threshold}$** | **$F_{threshold}<F<F_{limit}$** | **$F>F_{limit}$** |
| **Biomass (B)[2]** | **$B>B_{target}$** | Sustainable | Monitor closely | Restrict fishing | Very restricted fishing |
| | **$B_{target}>B>B_{threshold}$** | Monitor closely | Monitor closely | Restrict fishing | Very restricted fishing |
| | **$B_{threshold}>B>B_{limit}$** | Restrict fishing | Restrict fishing | Restrict fishing | Very restricted fishing |
| | **$B<B_{limit}$** | Close | Close | Close | Close |

**Table 7.2.** Workable decision rules based on a Target, Threshold, and Limit reference points for Level 3 assessments based on fishing mortality, *F* (from Wise *et al.* 2007). Applies to assessments of spangled emperor, goldband snapper in this report.

| Fishing mortality (F) estimates are available but no biomass estimates | Provides for a decision rule of fishing pressure |
|---|---|
| $F<F_{target}$ | Fishing effort (and/or catches) may increase |
| $F_{target}<F<F_{threshold}$ | Fishing effort (and/or catches) to remain constant |
| $F_{threshold}<F<F_{limit}$ | *Fishing effort (and/or catches) reduced eg 0%-50% |
| $F>F_{limit}$ | *Fishing effort (and/or catches) reduced eg 50%-100% |

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

### 7.1.1 Level 3 'weight-of-evidence' assessments.

A stock assessment provides the risk to the resource against Target, Threshold and Limit reference points (e.g., Wise *et al.* 2007; Smith *et al.* 2008). For fish resources where adequate information exists to enable a high level (e.g., Level 5: integrated model) assessment, the level of management response to ensure ongoing sustainability of the resource, based on current risk and projected future harvest scenarios, can be relatively specific. However in data limited situations there is typically greater uncertainty in assessment results and so coarser levels of management response are more appropriate (e.g., Wise *et al.* 2007; Table 7.2).

To address this issue for data-limited fisheries, the Department has adopted a 'weight-of-evidence' approach (Wise *et al.* 2007). This approach involves combining information on vulnerability status with historical data on levels of catch, effort, and quantified stock status, such as from catch curve analysis (and quantified uncertainty about those estimates), to provide advice on the overall risk to sustainability for the fishery resource and an appropriate level of management response.

Based on a review of approaches adopted by other agencies (Hobday *et al.* 2010; Patrick *et al.* 2010) and internal workshops, the criteria used to determine vulnerability status have been revised (Appendix 6). Emphasis was placed on not "over-weighting" related vulnerability attributes for determining vulnerability status (Morison, 2012). This was done by evenly weighting vulnerability attributes classified as either "productivity" or "susceptibility" attributes. Productivity attributes are those that influence the intrinsic nature of the resource, and are typically related to the life history parameters. Susceptibility attributes are those that are reflected in the removal portion of a resource, and contribute to its overall catchability. Additionally, following Patrick *et al.* (2010), uncertainty in categorising vulnerability attributes was made explicit. Unlike the other studies upon which these methods were derived (e.g., Stobutzki *et al.* 2001; Patrick *et al.* 2010; Hobday *et al.* 2011), the outcome of scoring each attribute in terms of its relative vulnerability (i.e., "Low", "Medium", "High") was not used independently as a measure of risk to stock status, but instead was incorporated as a component of the 'weight-of-evidence' stock assessment framework to provide a more complete assessment of risk consistent with international standards (Wise *et al.* 2007).

The different types of vulnerability attributes convey different aspects of research advice to management concerning sustainability risk. Overall vulnerability is a combination of productivity and susceptibility scores, and so is useful for providing an overall score. A key distinction is that since susceptibility attributes are related to catchability and this catchability can be managed, susceptibility scores could be particularly useful for determining, specifically, how overall vulnerability may be reduced. This may be done to address an overall sustainability risk identified by a 'weight-of-evidence' assessment because a reduction in susceptibility would also result in a lowering of overall vulnerability and risk profile. Productivity attributes, on the other hand, are those inherent aspects of population biology that cannot be readily managed, and therefore more appropriately represent the level of intrinsic resilience to effects of fishing that cause a significant increase in risk profile. Therefore, the revision of vulnerability attributes (Appendix 6) has resulted in the overall productivity score now representing that component of vulnerability used for refining the decision rules in Table 7.2, in line with the Department's existing weight of evidence framework (Wise *et al.* 2007).

## 7.2 Summary of current stock status and implications for management

The information presented here provides the basis for fisheries managers to determine (with reference to above decision rules; Tables 7.1, 7.2) if, and to what extent, management of catch and/or effort might be required for each of the indicator stocks, and, accordingly, for the corresponding suite(s) of inshore (20-250m) demersal scalefish that they represent.

### 7.2.1 Pink snapper

Oceanic and inner gulf pink snapper stocks already have appropriate monitoring and management strategies in place. For a more detailed summary of current stock status, refer to Sections 6.3.3.1, 6.3.4.1.

The spawning biomass of the oceanic pink snapper stock was estimated (based on the 2009 assessment) to be above the Threshold level. Under current levels of catch, the spawning biomass is projected to reach the Target level by 2014 (i.e. spawning biomass at 40% of unexploited level, Jackson *et al*. 2010a). Catches taken by the commercial GDSF (previously SBSF) will continue to be monitored, and the stock assessment updated every 3-5 years, until the spawning stock has recovered to the Target level.

Inside Shark Bay, the spawning biomasses of the Eastern Gulf and Denham Sound pink snapper stocks were estimated (based on the 2008 assessment) to be above the Target level (i.e. spawning biomass at 40% of unexploited level). In contrast, the spawning biomass of the Freycinet Estuary stock was estimated (based on the 2008 assessment) at around the Threshold level (i.e. spawning biomass at 30% of unexploited level) but was recovering and was projected to reach Target level (i.e. spawning biomass at 40% of unexploited level) by 2012. All three inner gulf stocks will continue to be monitored, and the respective stock assessments updated every 3-5 years until the Freycinet Estuary stock has recovered to the Target level.

### 7.2.2 Spangled emperor

#### 7.2.2.1 Relative vulnerability status

In accordance with the 'weight-of-evidence' approach (see 7.1.1) for Level 3 or lower assessments, the inherent vulnerability of stocks and trends in catches and effort (Section 6.1) can be used by managers to fine-tune potential reductions in catch and effort as indicated from assessments of fishing mortality (see Section 6.3.2). The following tables summarise vulnerability attributes for spangled emperor in the North Gascoyne (Table 7.3) and South Gascoyne (Table 7.4) to determine vulnerability status. Data are summarised largely from material presented in Section 5.2 and Section 6 of this report. Overall vulnerability status is determined to be Medium for spangled emperor stocks in the Gascoyne Coast Bioregion.

**Table 7.3.** Relative vulnerability for spangled emperor, North Gascoyne.

| Attribute | Type | Evidence | Level |
|---|---|---|---|
| Growth (von Bertalanffy K) | Productivity | $K = 0.282\ yr^{-1} \pm 0.019$ 95% CI | Low |
| Trophic level** | Productivity | Trophic level = 3.3 (Froese and Pauly, 2011) | Medium |
| Longevity (maximum age = $t_{max}$) | Productivity | $t_{max}$ = 30.75 yr | Medium |
| Age at maturity ($t_{mat}$) | Productivity | $t_{mat}$ = 3.5 yr (Marriott *et al.* 2010) | Medium |
| Selectivity and availability | Susceptibility | $t_c$ = 0.7 yr (Section 6.3.3.2.1); $t_c < t_{mat}$. High proportion of the population can be caught close to shore, including juveniles. | High |
| Schooling/aggregation behaviour | Susceptibility | Peak spawning: September - November (3 months) (Section 5.2.4). Form dense aggregations during the spawning season that are highly catchable (R. J. Marriott, *pers. obs.*). No clear relationship established with lunar phase and spawning as yet although investigations into fine scale spawning dynamics is underway (Department of Fisheries WA unpublished data). | Medium |
| Mode of reproduction | Susceptibility | Functional gonochore with prematurational protogyny (Marriott *et al.* 2010) | Medium |
| Fecundity (per spawning event) at age of first maturity | Productivity | Batch fecundity estimates available for fish aged 8-15 yr (Section 5.2.4) but not for fish near age of $t_{mat}$. No confident batch fecundity relationship with age is available as yet. | Unknown |
| Recruitment variability | Productivity | Insufficient data | Unknown |
| Breeding strategy and dispersal of eggs/larvae | Productivity | Broadcast spawner (Marriott *et al.* 2010). Larval dispersal sufficient to maintain genetic mixing throughout this stock (Johnson *et al.* 1993; Berry *et al.* 2012) | Low |
| Distribution and movement of adults | Susceptibility | Broad distribution throughout study region to approx. 80 m depth (coral reef habitat). Limited adult mixing. Average home range is approximately 3 nm (~5.4 km). | High |
| Post-capture mortality | Susceptibility | Good (e.g., Moran *et al.* 1993). Likely better in shallow water (< 10 m), where many recreational catches occur and where many fish smaller than MLL reside. | Low |
| Resilience to other sources of mortality | Productivity | Habitat dependence: Not likely an obligate coral dwelling species but inter-reefal habitats are important for benthic food sources. Sea grass habitats are important to juvenile settlement (Arvedlund and Takemura 2006); some juvenile settlement areas are close to shore in the Ningaloo MP (R.J. Marriott, *pers. obs.*). | Medium |
| Level of Uncertainty | | | Low |
| Overall Productivity | | | Medium |
| Overall Susceptibility | | | Medium-High |
| **Overall Vulnerability** | | | **Medium** |

**Table 7.4.** Relative vulnerability for spangled emperor, South Gascoyne.

| Attribute | Type | Evidence | Level |
|---|---|---|---|
| Growth (von Bertalanffy K) | Productivity | $K$ = 0.179 $yr^{-1}$ ± 0.027 95% CI | Medium |
| Trophic level** | Productivity | Trophic level = 3.3 (Froese and Pauly, 2011) | Medium |
| Longevity (maximum age = $t_{max}$) | Productivity | $t_{max}$ = 30.75 yr | Medium |
| Age at maturity ($t_{mat}$) | Productivity | $t_{mat}$ = 3.5 yr (Marriott *et al.* 2010) | Medium |
| Selectivity and availability | Susceptibility | $t_c$ unknown. Mostly distributed around offshore islands in the south and only accessible to shore-based fishers in north. | Medium |
| Schooling/aggregation behaviour | Susceptibility | Peak spawning: 3 month period (Section 5.2.4). Form dense aggregations during the spawning season that are highly catchable (R. J. Marriott, *pers. obs.*). No clear relationship established with lunar phase and spawning as yet although investigations into fine scale spawning dynamics is underway (Department of Fisheries WA unpublished data). | Medium |
| Mode of reproduction | Susceptibility | Functional gonochore with prematurational protogyny (Marriott *et al.* 2010) | Medium |
| Fecundity (per spawning event) at age of first maturity | Productivity | Batch fecundity estimates available for fish aged 8-15 yr (Section 5.2.4) but not for fish near age of $t_{mat}$. No confident batch fecundity relationship with age is available as yet. | Unknown |
| Recruitment variability | Productivity | Insufficient data | Unknown |
| Breeding strategy and dispersal of eggs/larvae | Productivity | Broadcast spawner (Marriott *et al.* 2010). Larval dispersal sufficient to maintain genetic mixing throughout this stock (Johnson *et al.* 1993; Berry *et al.* 2012) | Low |
| Distribution and movement of adults | Susceptibility | Broad distribution throughout study region to approx. 80 m depth (coral reef habitat). Limited adult mixing. Average home range is approximately 3 nm (~5.4 km). | High |
| Post-capture mortality | Susceptibility | Good (e.g., Moran *et al.* 1993). Likely better in shallow water (< 10 m), where many recreational catches occur and where many fish smaller than MLL reside. | Low |
| Resilience to other sources of mortality | Productivity | Habitat dependence: Not likely an obligate coral dwelling species but inter-reefal habitats are important for benthic food sources. Sea grass habitats are important to juvenile settlement (Arvedlund and Takemura 2006); some juvenile settlement areas are close to shore in the Ningaloo MP (R.J. Marriott, *pers. obs.*). | Medium |
| Level of Uncertainty | | | Low |
| Overall Productivity | | | Medium |
| Overall Susceptibility | | | Medium |
| **Overall Vulnerability** | | | **Medium** |

#### 7.2.2.2 Summary of quantitative assessments

Estimates of fishing mortality for spangled emperor north of Point Maud (North Gascoyne) in 2007/08 ranged from $0.9M$ to $1.7M$, which all exceeded the Threshold reference level (i.e., $F >> M$). Some of these estimates marginally exceeded the Limit reference level ($F > 1.5M$), which was above the international benchmark in terms of risk to sustainability for species with intermediate and long life spans (i.e., longevity: > 10 yr; Tables 7.3, 7.4). The yield- and egg production-per recruit was determined to be minimally impacted at this level of $F$. However, the per-recruit analyses did not account for unknown temporal dynamics of the fish population so results should be treated only as preliminary estimates until sufficient data is available for a more comprehensive analysis.

The level of fishing mortality for spangled emperor south of Point Maud (South Gascoyne), including waters offshore from Shark Bay, ranged from ~0 to $0.8M$, which included estimates that were either below the Target reference level ($F < 2/3M$) or between the Target and Threshold reference levels ($2/3M < F < M$). Based on the behavioural attributes and catch history of this species suggests that the part of the spangled emperor stock in the South Gascoyne is currently (as at 2007/08) being fished at a sustainable rate.

That the level of fishing mortality was higher in the North than in the South Gascoyne reflected the higher levels of historical commercial catches (i.e., from late 1980s to mid-1990s) and higher levels of current recreational and charter catches, from the northern part of the Bioregion for this species (Section 6.1; Table 7.5). Historically, the levels of spangled emperor catch in the South Gascoyne were higher across all sectors; most conspicuously for the commercial sector, which has now shifted its fishing effort to targeting deeper-water species (e.g., goldband snapper) when not targeting pink snapper.

At the Bioregion level, however, there exists one single genetic stock of spangled emperor. If we assume similar abundances of spangled emperor in the North and South Gascoyne, the Bioregion level of $F$ should be approximately mid-way between presented estimates of $F$ for the North and South Gascoyne. In that case, the median of those presented estimates of $F$, which lies between the Target and Threshold reference levels ($2/3M < F < M$), would be an appropriate representation for spangled emperor at the Bioregion level.

Steady declines in the commercial catch rates were observed for spangled emperor in both the North and South Gascoyne, however there was not enough evidence to confirm whether these declines were a result of declines in the relative abundance of spangled emperor populations, shifts in fishing practices, or other factors influencing catch rates.

**Table 7.5.** Summary of quantitative assessments for spangled emperor stocks in the Gascoyne Coast Bioregion*.

| North Gascoyne | Low | Medium | High |
|---|---|---|---|
| Age/Length distributions (Fishing mortality estimates where $F>F_{threshold}$ and $F>F_{limit}$) | | | ✓* |
| Effort/Catch | | ✓ | |
| **South Gascoyne** | **Low** | **Medium** | **High** |
| Age/Length distributions (Fishing mortality estimates where $F>F_{threshold}$ and $F>F_{limit}$) | ✓ | | |
| Effort/Catch | ✓ | | |

* Note: Estimates of $F$ only marginally exceeded the $F_{Limit}$ level of 1.5$M$ and although age distributions were not significantly different from the main analysis presented in Section 6.3.2, $F$ estimates ranged between $F_{Threshold}$ and $F_{Limit}$ when data were organised by different year groupings (Appendix 3).

#### 7.2.2.3 Implications for management

Integrating these results with the biological attributes, limited data on catch history and referring to decision rules in Table 7.2 suggests that there was localised over-fishing of spangled emperor in the North Gascoyne in 2007/08 and that the overall level of fishing effort or catch (i.e., recreational and charter) needs to be reduced by 0% to 100%. The reason for the wide range of reduction is that the $F$ estimate marginally exceeded the Limit level (corresponding to a 50%-100% reduction), although uncertainty levels included estimates that were between the Threshold and Limit levels, which corresponded to a 0-50% reduction (see Table 7.2). For perspective, estimates of $F$ for pink snapper ranged from 2.3$M$ to 7.3$M$ and estimates for dhufish ranged from 1.0$M$ to 2.1$M$ for recent assessments of demersal scalefish stocks in the West Coast Bioregion, where a 50-100% reduction was advised (Wise *et al.* 2007). In comparison, 2007/08 estimates of $F$ for spangled emperor in the North Gascoyne ranged from 0.9$M$ to 1.7$M$.

Given the lack of increase in North Gascoyne catch levels over the 10 year period since sanctuary zones were first established but an increase in $F$ over this time suggests that in addition to there being no evidence of spillover benefits to the stock outside of sanctuary zones in the Ningaloo Marine Park, it is possible that the concentration of fishing effort into a smaller area may have exacerbated localised depletions. This inference is consistent with the findings of an independent simulation study (Little *et al.* 2011).

That the level of fishing mortality for spangled emperor south of Point Maud (South Gascoyne) was below the Threshold level ($F<M$) indicates that the spangled emperor catch should not increase above the 2007 level in the South Gascoyne and that ongoing monitoring is required (Wise *et al.* 2007).

At the Bioregion level, if we assume similar abundances of spangled emperor in the North and South Gascoyne, the spangled emperor breeding stock in 2007/08 was estimated to be at an acceptable level, noting significant reductions in the relative numbers of older (breeding age) spangled emperor in the North Gascoyne, outside of sanctuary zones, due to localised depletions. It is noteworthy that the component of the breeding stock in the North Gascoyne residing within sanctuary zones of the Ningaloo Marine Park (and not assessed) may contribute towards buffering against potential recruitment overfishing. Although differences in growth were

* Note: stock assessments reported here were undertaken for north and south Gascoyne separately, based on data availability: currently there is no evidence to suggest that these represent separate stocks, rather, spangled emperor in the Gascoyne constitute a single genetic stock.

observed between the North and South Gascoyne, the overall inherent biological productivity for spangled emperor in the Bioregion was Medium. This suggests that, if an appropriate range of catch reduction is selected (see above) the level of reduction should be refined towards the middle of that range.

### 7.2.3 Goldband snapper

#### 7.2.3.1 Relative vulnerability status

In accordance with the 'weight-of-evidence' approach (Wise *et al.* 2007) for lower-level assessments (i.e., lower than a Level 5 assessment, as done for pink snapper stocks), the inherent vulnerability of stocks and trends in catches and effort (Section 6.1) can be used by managers to fine-tune potential reductions in catch and effort as indicated from assessments of fishing mortality (see Section 6.3.3). The following table summarises productivity and susceptibility attributes for goldband snapper in the Gascoyne Coast Bioregion to indicate inherent vulnerability status (Table 7.6). Data are summarised largely from material presented in Section 5.3 and Section 6 of this report. Overall vulnerability status is determined to be Medium for goldband snapper population(s) in the Gascoyne Coast Bioregion.

**Table 7.6.** Relative vulnerability for goldband snapper, Gascoyne Bioregion.

| Attribute | Type | Evidence | Level |
|---|---|---|---|
| Growth (von Bertalanffy K) | Productivity | $K$ = 0.302 $yr^{-1}$ ± 0.011 95% CI | Low |
| Trophic level** | Productivity | Unknown | Unknown |
| Longevity (maximum age = $t_{max}$) | Productivity | $t_{max}$ = 31.33 yr | High |
| Age at maturity ($t_{mat}$) | Productivity | $t_{mat}$ = 4.74 yr using the equation relating proportion mature at age ($Pmat_t$) to fork length ($FL_t$; mm) at age by Newman *et al.* (2001): $Pmat_t = \frac{1}{1+e^{-0.0442(FL_t-473)}}$ and the described relationship between *FL* at age *t* (Section 5.3.2.3). | Medium |
| Selectivity and availability | Susceptibility | $t_c$ = 5.6 yr (Section 6.3.3.3.2); $t_c > t_{mat}$. High overlap of stock with the fishery (i.e., those operators who target this species). | Medium |
| Schooling/aggregation behaviour | Susceptibility | Peak spawning: 4-5 months and not well defined given available data. Known to form highly catchable aggregations over hard bottom areas (Newman *et al.* 2001). | Medium |
| Mode of reproduction | Susceptibility | Gonochoristic | Low |
| Fecundity (per spawning event) at age of first maturity | Productivity | No data | Unknown |
| Recruitment variability | Productivity | Insufficient data | Unknown |
| Breeding strategy and dispersal of eggs/larvae | Productivity | Broadcast spawner (Newman *et al.* 2001). Studies elsewhere suggest pelagic larval dispersal may be limited to within 500km from source (Ovenden *et al.* 2004). | Medium |
| Distribution and movement of adults | Susceptibility | Restricted to tropical waters and depths from 60m to 250m. Likely limited adult mixing spatially and strong demersal habitat dependence (Newman *et al.* 2000; Ovenden *et al.* 2004; Blaber *et al.* 2005). | High |
| Post-capture mortality | Susceptibility | Likely to be sensitive to post-release mortality (Newman and Dunk 2003). | High |
| Resilience to other sources of mortality | Productivity | Distributed well offshore and away from major coastal anthropogenic influences. Likely to have strong demersal habitat dependence in relatively deep depths (Newman *et al.* 2000). Habitat condition unknown. | Unknown |
| Level of Uncertainty | | | Medium |
| Overall Productivity | | | Medium |
| Overall Susceptibility | | | Medium-High |
| **Overall Vulnerability** | | | Medium |

### 7.2.3.2 Summary of quantitative assessments

The level of fishing mortality for goldband snapper was below the Target reference level ($F < 2/3M$) for 2005 to 2007 levels of catch (Table 7.7). Since it was not possible to obtain a reliable time series of an index of abundance for this species, and given that the catch curve analyses were run for only 2 years of relatively recently-collected data, uncertainties in the catch curve analyses need to be considered. For instance, given that the targeting of goldband snapper, primarily by the commercial sector, has only occurred in recent years, the flow through of these catches to the age structure may not yet be complete. Further, the egg-per-recruit analysis demonstrated that any increases in $F$ or a decrease in age at selectivity would have a relatively large impact on egg-per-recruit for the stock.

**Table 7.7.** Summary of quantitative assessments for goldband snapper in the Gascoyne

| Gascoyne | Low | Medium | High |
|---|---|---|---|
| Age/Length distributions (Fishing mortality estimates where $F > F_{threshold}$ and $F > F_{limit}$) | ✓ | | |
| Effort/Catch | | ✓ | |

### 7.2.3.3 Implications for management.

According to the decision rules (Table 7.2), results from the catch curve analysis indicate that catches of goldband snapper may increase without exceeding the Target level of $F$ based on data collected to 2007/08. However, vulnerability of the species (Table 7.6) and the recent trend in increasing catches (from ~121 tonnes in 2007/08 to ~144 tonnes in 2008/09, Jackson *et al.* 2010a), increases the risks to sustainability. The uncertainties in the assessment and indicated sensitivity for egg production to be impacted from increasing levels of fishing mortality and potential decreasing size selectivity suggests that catches of goldband snapper should not increase beyond the 2007 level and that ongoing monitoring is required.

## 7.2.4 General comments

There were different historical approaches to monitoring and management of each of the indicator stocks (see Sections 4.5, 6.3). Therefore, different types ('Levels'; DoF 2011) of assessment ensued. Different issues have arisen for each of these indicator stocks from these assessments (Table 7.8).

It is appropriate to stress at this stage that the diversity of management considerations for each indicator species should be considered in context of managing the entire suite of demersal scalefish stocks in the Gascoyne Coast Bioregion, as is consistent with the IFM approach. Therefore, that the $F$ exceeded the Threshold level for spangled emperor in the North Gascoyne in 2007/08 suggests that the total level of catch of demersal scalefish across all sectors from the North Gascoyne (mostly recreational) be reduced according to the above listed decision rules. The $F$ values for goldband snapper and spangled emperor stocks in the South Gascoyne were within acceptable ranges as at 2007. For pink snapper, management measures to assist the recovery of the oceanic spawning stock (since 2004) and the three separate inner gulf spawning stocks (since 1998) have seen the spawning biomass of all four stocks reach levels either around or above the Threshold level. Thus there is no need for additional management of demersal scalefish catches over and above existing regulations on pink snapper catches in that region; however further monitoring of spangled emperor and goldband snapper stocks is advised. Additionally, it is likely that further increases in the efficiency of fishing (as demonstrated by commercial catches and catch rates for goldband snapper, Sections 6.1, 6.2) may occur. The uncertainties in the assessment and indicated sensitivity for egg production to be impacted from increasing levels of fishing mortality and potential decreasing size selectivity suggests that catches of goldband snapper should not increase beyond the 2007 level and that ongoing monitoring is required.

**Table 7.8.** Summary of species-specific estimates of *F* and, where available, spawning stock biomass, commensurate decision rules (Refer to Tables 7.2, 7.3) and, where appropriate, levels of reduction of effort and/or catch for those stocks. "Level of reduction within range" corresponds to the productivity score (i.e., "Low", "Medium" or "High"). Modified from Wise *et al.* (2007).

| **Pink snapper** | | | |
|---|---|---|---|
| **Location** | **Estimate of Spawning Biomass** | **Estimate of F** | **Decision rule** |
| Oceanic | BThreshold>B>BLimit | $F_{Threshold}<F<F_{Limit}$ | Target catch and/or effort level adjusted to the estimated sustainable catch level, in relation to current and forecasted stock status[1]. |
| Eastern Gulf | $B>B_{Target}$ | $F_{Threshold}<F<F_{Limit}$ | |
| Denham Sound | $B>B_{Target}$ | $F_{Threshold}<F<F_{Limit}$ | |
| Freycinet | $B_{Threshold}>B>B_{Limit}$ | $F_{Target}<F<F_{Threshold}$ | |

| **Spangled emperor** | | | |
|---|---|---|---|
| **Location** | **Estimate of F** | **Decision rule** | **Level of reduction within range** |
| North Gascoyne | $F>> F_{Threshold}$[2] | Catch/effort reduced by 0%-100%[2] | Medium [2] |
| South Gascoyne | $F<F_{Threshold}$ | Catch/effort to remain constant | n/a |

| **Goldband snapper** | | | |
|---|---|---|---|
| **Location** | **Estimate of F** | **Decision rule** | **Level of reduction within range** |
| South Gascoyne | $F<F_{Target}$ | Catch/effort to remain constant [3] | n/a |

[1] Sustainable catch level estimates correspond to current stock status, as determined with respect to $B_{Target}$, $B_{Threshold}$, $B_{Limit}$, $F_{Target}$, $F_{Threshold}$, $F_{Limit}$ reference points and, where applicable, to the forecasted recovery trend, as determined in context of its respective harvest strategy. Estimates are updated upon subsequent review of stock status when the assessment models are refitted to more recently collected data (catch, effort, catch-at-age, relative biomass).

[2] Localised overfishing was detected for spangled emperor outside of sanctuary zones of the Ningaloo Marine Park and so a localised reduction in catch/effort levels is advised. There remains, however, some uncertainty with relating the *F* estimates to being either above or below the Limit reference level and thus with the corresponding level of reduction to be applied. *F* estimates marginally exceeded the Limit level, corresponding to a 50-100% reduction, but uncertainty levels included estimates that were between the Threshold and Limit levels, correspond to a 0-50% reduction. A Medium productivity score suggests the reduction should be towards the middle of the suggested reduction range.

[3] Note this decision rule is more conservative than advised in Table 7.2. Given the high inherent vulnerability and recent history of catches we advise this more conservative decision rule, as a precautionary measure.

## 7.3 Implications for future monitoring and assessment

### 7.3.1 Pink snapper

The reproductive behaviour of pink snapper (i.e., aggregate in similar locations each year) makes spawning stocks inherently vulnerable to high levels of fishing. While current management of the recreational fishery in the inner gulfs mitigates the risk of overexploitation, monitoring of these stocks will continue, and the three separate stock assessments will be updated every 3-5 years until the Freycinet Estuary stock has recovered to the Target level. Current management of the commercial fishery directed at the oceanic pink snapper stock (TACC currently ca. 50% of the level it was 1990-2003) mitigates the risk of future overexploitation of the spawning aggregations. However, the current risk to continued stock recovery and on-going sustainability will remain if recreational and charter catches are allowed to increase significantly in the future. Thus, catches from all sectors for all four pink snapper stocks in the Bioregion need to be monitored into the future.

Recent work (Lenanton *et al.* 2009b) has identified the significance of post-release mortality on pink snapper in deeper (oceanic) waters (e.g. undersized fish in the commercial fishery, fish of all sizes in recreational fishery when bag limits have been achieved and fishing continues). This should be a key consideration for incorporating into future monitoring and stock assessments and may need to be specifically addressed through future management arrangements.

### 7.3.2 Spangled emperor

The implementation of sanctuary zones within the Ningaloo Marine Park (MP) and that spangled emperor are primarily a recreational catch species are key considerations for future monitoring and assessments.

Sanctuary zones have complicated the current assessments because it is unknown to what extent the absence of age structure information for fish that reside inside of sanctuary zones has influenced results, particularly for the North Gascoyne area. Age structure information was not available for fish residing within sanctuary zones because data were obtained from sampling the landed catches of recreational fishers, who are prohibited from fishing within sanctuary zones. The magnitude of any potential bias arising from this effect would depend on the level of fidelity of adults to remain within sanctuary zones and the amount of movement of fish from inside to outside of them. There is some evidence emerging to suggest that there are significantly more of the larger spangled emperor within than outside of sanctuary zones in the Ningaloo MP (Westera *et al.* 2003; Babcock *et al.* 2008; B. Fitzpatrick, unpublished data) and that the average home range of adults is approximately 3 km or less (Moran *et al.* 1993, Chateau and Wantiez 2008). These studies suggest that there may be limited movement of larger (older) spangled emperor beyond sanctuary zones and therefore the detected effect of fishing in the North Gascoyne presumably reflects effects on the component of the population that resided outside of the sanctuary zones only. In order to address such sources of uncertainty in future, data would need to be collected from both inside and outside of the sanctuary zones for analysis.

Obtaining representative recreational catch samples is generally more resource intensive than obtaining representative commercial catch samples. A sampling design for representative commercial catch sampling can be based around the few key landing ports, and sampling effort can be apportioned appropriately according to detailed spatial knowledge of catches and effort, which can be obtained from an analysis of data gathered from statutory logbook returns. Recreational catches, however, can be landed frequently by a large number of anglers and at many (and some remote) landing sites throughout the Bioregion, and there is a paucity of recreational catch and effort data upon which to base sampling strategies with appropriately apportioned sampling effort*. Representative recreational catch samples were obtained for assessing stock status in 2007/08 because biological catch sampling was integrated with sampling effort for the recreational fishing survey in that year, which was economically viable. This level of resourcing for obtaining representative recreational catch samples for routine monitoring of the spangled emperor stock, however, is not currently available.

### 7.3.3 Goldband snapper

A different growth trend and habitat (deeper depth distribution) for goldband snapper in the GCB as compared to that described for the Kimberley stock by Newman and Dunk (2003) suggests that there may be some other important differences in aspects of biology between these stocks. Further, previous work on stock structure has identified that gene flow can be limited at spatial scales of 500 km or less (Ovenden *et al.* 2004), so the stock in the GCB could be a separate stock to goldband snapper in the Kimberley, and possibly the Pilbara. Given its Medium-level vulnerability status, high estimated sensitivity of egg production to increases in fishing mortality and recent observed increases in catches across all sectors, this GCB stock should continue to be closely monitored. Further, relevant aspects of its biology, such as its size and age at maturity and recruitment dynamics, should be investigated for the GCB stock. An improved understanding of population dynamics for the GCB stock can then be used to evaluate inferences made in this report about the likely sustainability of fishing the GCB stock based on experience and knowledge gained from researching and monitoring the Kimberley stock, which has sustained a much longer history of commercial harvest.

Scope for improved levels of assessment will be greatly enhanced when a sufficient time series (i.e. 5-10 years) of data are available from the commercial statutory daily/trip logbooks, which were implemented for the SBSF from February 2008. This dataset will have an improved resolution for exploring spatiotemporal trends in catches and catch rates using statistical models and for potentially obtaining a standardised catch rate to use as an index of abundance. A reliable index of abundance could reduce uncertainty in future assessments by providing a useful additional performance measure and/or providing scope for the development of an integrated assessment model for this stock and thus a higher-level assessment. Improved species identification (i.e., distinguishing between goldband snapper, sharptooth snapper and rosy jobfish) and the identification of targeted fishing effort by the commercial operators in completing these returns and validation programs to check the accuracy of submitted returns will help to achieve this goal.

## 7.4 Summary of implications

1. At current (2007/08) levels of commercial catch and effort, the oceanic pink snapper stock is likely to continue to recover and reach the Target level ($B_{40}$) within the agreed timeframe (by 2014). However, recreational and charter catches will need to be monitored and management action may need to be taken if these catches increase, to ensure stock sustainability.

2. Depth-related discard mortality is likely significant with oceanic pink snapper across all sectors and needs be more adequately incorporated into future stock assessments.

* Noting, however, that the Department has since initiated a state-wide recreational fishing survey that commenced in 2011, with plans to continue this survey on a 2-yearly cycle.

3. At current (2007/08) levels of recreational catch and effort, risks to sustainability with inner gulf pink snapper stocks are considered to be acceptable. Under current arrangements, the Freycinet Estuary stock should reach the Target level within the agreed timeframe (by 2012). However, recreational fishing activity in the inner gulfs will need to continue to be monitored in order to detect any future effort increases, e.g. due to displaced effort as a result of restrictions imposed in other fisheries in WA (e.g. West Coast Demersal Scalefish Fishery).

4. Estimates of fishing mortality on spangled emperor in the North Gascoyne (north of Point Maud) for 2007/08 all exceeded the Threshold level and some of those estimates marginally exceeded the Limit level, indicating localised overfishing is likely to be occurring, despite no recent increase in catches and implementation of sanctuary areas. This suggests, according to the Decision rules developed by Wise *et al.* (2007) that fishing catches and/or effort need to be reduced from 0% to 100%. The wide range of reduction is attributed to uncertainty with relating $F$ estimates to being either above or below the Limit reference level.

5. Additional monitoring and assessment of the spangled emperor stock in the North Gascoyne is advised, given the estimated level of fishing mortality in 2007/08. Ongoing monitoring should ideally sample population age structures inside and outside of sanctuary zones and account for the resource-intensive nature of recreational catch sampling in this Bioregion.

6. Spangled emperor in the South Gascoyne (south of Point Maud) were assessed as being fished at a sustainable rate in 2007.

7. If we assume similar abundances of spangled emperor in the North and South Gascoyne, the breeding stock for the whole Gascoyne Bioregion is likely to be at an acceptable level, noting significant reductions in the relative numbers of older (breeding age) spangled emperor in the North Gascoyne, outside of sanctuary zones.

8. Goldband snapper in the South Gascoyne was assessed as currently (as at 2007/08) being fished at a sustainable rate. Given increases in commercial catches of goldband snapper taken since 2007, ongoing monitoring is advised to ensure that the rate of fishing does not become unsustainable. Also, given that the targeting of goldband snapper has only occurred in recent years, the flow through of these catches to the age structure may not yet be complete and therefore subsequent stock assessments of sampled age structures are required to confirm the observed risk profile.

9. Future monitoring and assessment of the goldband snapper stock should consider additional research into describing relevant aspects of its biology for the GCB, such as the size and age at maturity and recruitment dynamics. Biological parameter estimates are required for the GCB stock because assessments in this report assumed that many of the unknown biological parameters were the same as estimates previously reported for the Kimberly stock. These biological parameter estimates assumed for the GCB stock, however, may differ to those reported for the Kimberly stock, given that differences in growth trends were observed in this report (Section 5.3), and known differences in climate and depth profiles inhabited by goldband snapper, exist between these areas.

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# 9.0 Appendices

## Appendix 1. Gascoyne demersal scalefish species that feature significantly in commercial, recreational and charter catches. Sources are CAES, charter vessel returns and recreational boat-fishing surveys. Species codes are those used in CAES, common names are CAAB names. Indicator species are in bold.

**Table A1.**

| Species Code | Family name | Common Name | Scientific Name |
|---|---|---|---|
| 346000 | Caesionidae | Fusiliers | *Caesio, Pterocaesio spp.* |
| 320000 | Glaucosomatidae | Western Australian Dhufish | *Glaucosoma hebraicum* |
| 320001 | Glaucosomatidae | Northern Pearl Perch | *Glaucosoma buergeri* |
| 350000 | Haemulidae | Sweetlips | *Plectorhinchus spp.* |
| 350003 | Haemulidae | Painted Sweetlips | *Diagramma labiosum* |
| 384005 | Labridae | Bluespotted Tuskfish | *Choerodon cauteroma* |
| 384010 | Labridae | Blackspot Tuskfish | *Choerodon schoenleinii* |
| 384072 | Labridae | Blue Tuskfish | *Choerodon cyanodus* |
| 384904 | Labridae | Pigfishes, General | *Bodianus spp.* |
| 384999 | Labridae | Baldchin Groper | *Choerodon rubescens* |
| 351001 | Lethrinidae | Blue-Spotted Emperor | *Lethrinus punctulatus* |
| 351004 | Lethrinidae | Longnose Emperor | *Lethrinus olivaceus* |
| 351005 | Lethrinidae | Robinson’s Seabream | *Gymnocranius grandoculis* |
| 351006 | Lethrinidae | Grass Emperor | *Lethrinus laticaudis* |
| 351007 | Lethrinidae | Redspot Emperor | *Lethrinus lentjan* |
| **351008** | **Lethrinidae** | **Spangled Emperor** | ***Lethrinus nebulosus*** |
| 351009 | Lethrinidae | Redthroat Emperor | *Lethrinus miniatus* |
| 351012 | Lethrinidae | Spotcheek Emperor | *Lethrinus rubrioperculatus* |
| 351013 | Lethrinidae | Yellowtail Emperor | *Lethrinus atkinsoni* |
| 351031 | Lethrinidae | Variegated Emperor | *Lethrinus variegatus* |
| **346002** | **Lutjanidae** | **Goldband Snapper** | ***Pristipomoides multidens*** |
| 346004 | Lutjanidae | Red Emperor | *Lutjanus sebae* |
| 346005 | Lutjanidae | Crimson Snapper | *Lutjanus erythropterus* |
| 346007 | Lutjanidae | Saddletail Snapper | *Lutjanus malabaricus* |
| 346010 | Lutjanidae | Darktail Snapper | *Lutjanus lemniscatus* |
| 346011 | Lutjanidae | Stripey Snapper | *Lutjanus carponotatus* |
| 346012 | Lutjanidae | Moses Snapper | *Lutjanus russelli* |
| 346017 | Lutjanidae | Chinamanfish | *Symphorus nematophorus* |
| 346019 | Lutjanidae | Sharptooth Jobfish | *Pritstipomoides typus* |
| 346027 | Lutjanidae | Green Jobfish | *Aprion virescens* |
| 346029 | Lutjanidae | Red Bass | *Lutjanus bohar* |
| 346030 | Lutjanidae | Golden Snapper | *Lutjanus johnii* |
| 346031 | Lutjanidae | Tang’s Snapper | *Lipocheilus carnolabrum* |
| 346032 | Lutjanidae | Rosy Snapper | *Pristipomoides filamentosus* |

| Species Code | Family name | Common Name | Scientific Name |
|---|---|---|---|
| 346040 | Lutjanidae | Yellowlined Snapper | *Lutjanus rufolineatus* |
| 346910 | Lutjanidae | Perch, Red, Maroon Sea Perch | *Lutjanus spp.* |
| 346912 | Lutjanidae | Mangrove Jack | *Lutjanus argentimaculatus* |
| 346914 | Lutjanidae | Ruby Snapper | *Etelis carbunculus* |
| 346003 | Lutjanidae | Seaperch, Striped | *Lutjanus vitta* |
| 311006 | Polyprionidae | Hapuku | *Polyprion oxygeneios* |
| 311170 | Polyprionidae | Bass Groper | *Polyprion americanus* |
| 326000 | Priacanthidae | Bigeye | *Priacanthus spp.* |
| 386000 | Scaridae | Parrotfish | *Scarus spp.* |
| 354001 | Scianidae | Mulloway | *Argyrosomus japonicus* |
| 311007 | Serranidae | Goldspotted Rockcod | *Epinephelus coioides* |
| 311009 | Serranidae | Yellowspotted Cod | *Epinephelus areolatus* |
| 311012 | Serranidae | Barcheek Coral Trout | *Plectropomus maculatus* |
| 311014 | Serranidae | Blacktip Rockcod | *Epinephelus fasciatus* |
| 311021 | Serranidae | Flowery Rockcod | *Epinephelus fuscoguttatus* |
| 311022 | Serranidae | Chinaman Rockcod | *Epinephelus rivulatus* |
| 311040 | Serranidae | Potato Rockcod | *Epinephelus tukula* |
| 311041 | Serranidae | Duskytail Groper | *Epinephelus bleekeri* |
| 311045 | Serranidae | Tomato Rockcod | *Cephalopholis sonnerati* |
| 311058 | Serranidae | Rankin Cod | *Epinephelus multinotatus* |
| 311063 | Serranidae | Birdwire Rockcod | *Epinephelus merra* |
| 311078 | Serranidae | Common Coral Trout | *Plectropomus leopardus* |
| 311083 | Serranidae | Coral Rockcod | *Cephalopholis miniata* |
| 311150 | Serranidae | Blackspotted Rockcod | *Epinephelus malabaricus* |
| 311152 | Serranidae | Eightbar Grouper (Grey Banded Cod) | *Hyporthodus octofasciatus* |
| 311166 | Serranidae | Yellowedge Coronation Trout | *Variola louti* |
| 311903 | Serranidae | Cod, Spotted | *Epinephalus microdon/ areolatus/bilobatus* |
| 311904 | Serranidae | Radiant Rockcod/Comet Grouper | *Epinephelus radiatus/ morrhua* |
| **353001** | **Sparidae** | **Snapper, Pink** | ***Pagrus auratus*** |
| 353002 | Sparidae | Yellowback Bream | *Dentex tumifrons* |
| 353006 | Sparidae | Frypan Bream | *Argyrops spinifer* |
| 118000 | Synodontidae, Harpodontidae | Lizardfishes & Grinners | *Synodus spp., Saurida spp.* |
| 264004 | Zeidae | John Dory | *Zeus faber* |

## Appendix 2. Datasheets for collecting catch and effort data.

**i. Monthly returns for Trap and Line: Commercial. Monthly summary sheets not shown.**

Original post to Department of Fisheries Duplicate - retain for your records

Office Use

### Trap and line: catch and effort return

Fish Resources Management Regulations 1995 Regulation 64

| Year | Month | Boat registration LFB | Boat name | |
|---|---|---|---|---|
| Fishing Boat Licence FBL | | Managed fishery licence(s) MFL | | |
| Anchorage | | Master's CFL No. | Master's name (Authorisation holder or agent) | |
| Months you propose not to fish | | Phone no. | Address | |
| No. days fished. | Crew number (inc master) | Fuel purchased (litres) | I certify that the information on this form is correct (Master, authorisation holder or agent) | Date signed |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Fishery eg. NDS, SBS (one fishery per column) | | | | | | Fishery eg. WL, EXEM | | |
| *If applicable* Zone fished (one zone per column) | | | | | | *If applicable* Zone fished | | |
| Trap and line methods eg. LL (one method per column) | | | | | | Other methods eg. HN | | |
| Block number (one block per column) | | | | | | Block number | | |
| Days fished | | | | | | Days fished | | |
| Hours fished per day | | | | | | Hours fished per day | | |
| Pots/traps pulled per day | | | | | | Pots/traps pulled per day | | |
| Hooks per day | | | | | | Hooks per day | | |
| Shots/pulls per day | | | | | | Shots/pulls per day | | |
| | | | | | | Net length (m) per shot | | |
| | | | | | | Mesh size range (mm) | | |

| Species (include all retained catch) | Condition codes | kg | kg | kg | kg | Species (include all retained catch) | Condition codes | kg | kg |
|---|---|---|---|---|---|---|---|---|---|
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| Dealer/processor | Crew names |
|---|---|
| Have you had an interaction with a protected species? Yes ☐ No ☐ If yes, was animal released Alive ☐ Dead ☐ | Species, location and other comments |

Notification of months when no fishing occurred is required on this form. A signed facsimile of this form may be submitted

## ii. SBSF Daily trip returns: Commercial

**Shark Bay Snapper Managed Fishery Daily Trip Logsheet** SBS
**Fish Resources Management Regulations 1995 Regulation 64**

| OFFICE USE ONLY | Month Year | LFB | BOAT NAME | NO FISHING THIS MONTH? *(If so, please tick box):* ☐ |
|---|---|---|---|---|

| DATE AND LOCATION OF SESSION | | | | |
|---|---|---|---|---|
| Day of month | | | | |
| Block number* | | | | |
| GPS coordinates* | S | S | S | S |
| | E | E | E | E |
| **FISHING GEAR USED DURING SESSION** | | | | |
| Method** | | | | |
| Number of lines | | | | |
| Hooks per line | | | | |
| No. of dropline sets | | | | |
| Hours spent searching | | | | |
| Hours spent fishing | | | | |
| **SPECIES SPECIFICALLY TARGETED DURING SESSION** | | | | |
| Pink Snapper (tick) | ☐ | ☐ | ☐ | ☐ |
| Goldband Snapper (tick) | ☐ | ☐ | ☐ | ☐ |
| Other (write name) | | | | |

| DETAILS FOR ENTIRE TRIP *(Fill in once on first sheet of trip)* | |
|---|---|
| Trip start date: | / / |
| start time: | ___:___ AM / PM |
| Port - Start: | |
| Trip end date: | / / |
| end time: | ___:___ AM / PM |
| Port - End: | |
| Skipper: | |
| CFL: | Ph: |
| Crew | 1. |
| | 2. |
| | 3. |
| | 4. |
| | 5. |
| OR: Same crew as last trip? ☐ **YES** | |

| ESTIMATED CATCH IN WEIGHT AND/OR NUMBERS OF FISH DURING SESSION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **NIL CATCH** (tick) | ☐ | | ☐ | | ☐ | | ☐ | |
| **SPECIES** | No. | Weight | No. | Weight | No. | Weight | No. | Weight |
| Pink Snapper | | kg | | kg | | kg | | kg |
| Goldband Snapper | | kg | | kg | | kg | | kg |
| Rosy Snapper | | kg | | kg | | kg | | kg |
| Ruby Snapper | | kg | | kg | | kg | | kg |
| Redthroat Emp. (Sweetlip) | | kg | | kg | | kg | | kg |
| Spangled Emperor | | kg | | kg | | kg | | kg |
| Red Emperor | | kg | | kg | | kg | | kg |
| | | kg | | kg | | kg | | kg |
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| | | kg | | kg | | kg | | kg |
| | | kg | | kg | | kg | | kg |
| | | kg | | kg | | kg | | kg |
| **PROTECTED SPECIES INTERACTIONS EXPERIENCED ON TRIP ***** | | | | | | | | |
| Species | | | | | | | | |
| Alive (A) or Dead (D) circle | A | D | A | D | A | D | A | D |
| **WEATHER AND/OR SEA STATE CONDITIONS — OPTIONAL (CIRCLE)** | | | | | | | | |
| (0=Ideal, 1=Average, 2=Poor) | 0 1 2 | | 0 1 2 | | 0 1 2 | | 0 1 2 | |

| TRIP LANDED WEIGHTS | |
|---|---|
| Condition** | Total Weight |
| | kg |
| | kg |
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Dealer/Processor:

Fuel used (L):

**General comments**

| **Signed** | |
|---|---|
| **Dated** | |
| **Position held** | |

Notes
* You have the option of recording Block Number (to nearest 10 nautical miles) OR GPS for location. See cardboard divider for example.
** Codes for Method (e.g. Hydraulic reel = HY) and Condition (e.g. Whole fish = WH) on cardboard divider
*** Protected species include: turtles, some sharks (e.g. Whale Shark, Great White, Grey Nurse, Speartooth, Northern River Shark, Freshwater Sawfish), seals and sea-lions, whales, dolphins, dugongs, sea birds, sea snakes, crocodiles, handfish, pipefishes, seahorses and seadragons. Please record details & report to DEW (ph: 1800 641 806)

**iii. Charter fishing logbook return. Monthly summary sheets not shown.**

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 | |
| SPV/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) |
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| I certify that the information on this form is correct. | Signature | Date |
|---|---|---|
| | Print name | Contact Number |

**iv. Recreational Fishing Survey interview forms.**

Interviewer's Name: ______________________________

Date: ____________ Start Time(24hr): ____________ Finish Time(24hr): ____________

Area: ____________________ Boat Ramp: ____________________

ENVIRONMENTAL DATA

Wind:

| Calm 1 | Light 2 | Mod 3 | Strong 4 | Gale 5 |
|---|---|---|---|---|

| Direction |
|---|
| |

Water:

| Calm 1 | Slight 2 | Mod 3 | Rough 4 | V. Rough 5 |
|---|---|---|---|---|

Cloud Cover:

| Cloud % |
|---|
| |

Rainfall:

| Nil 1 | Light 2 | Mod 3 | Heavy 4 |
|---|---|---|---|

| Boat Launches | | | | Boat Retrievals | | | | Total Number of Trailers | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Type | Time | Type | Time | Type | Time | Type | At Start | At Finish |
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Boat Types
P: Power boat
Y: Yacht
O: Other

Date: ________ Location: ______________________ Boat Reg. No.: ________________

| Interview Time | Boat (Pwr/Yacht/Charter/Othr) | Boat Departure Time | Fish/Dive/Snorkel/Other | Number in Boat | Number of Females in Boat | Age Group of Interviewee | Home Postcode of Interviewee | Length of Boat (ft/m) | Member Angling Club (Yes/No) | Time Spent Fishing (decimal hrs) | Block Number | Number of Lines Used | Number and type of nets - Crab,Set, Haul,cAst, Pots | Number of Times Interviewed Before |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| | | | | FISHERS ONLY | | | | | | | | | | |

| Species | Number Kept | Number Released | Taken by Sharks | Under/Over size Kept | Species Targeted________ Measurements (mm) |
|---|---|---|---|---|---|
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# 2007/08 GASCOYNE RECREATIONAL BOAT SURVEY
# BOAT RAMP FORM

Interviewer's Name: ______________________________

Date: ____________ Start Time(24hr): ____________ Finish Time(24hr): __________

District: ______________________ Boat Ramp: ______________________

ENVIRONMENTAL DATA

Wind:

| Calm | Light | Mod | Strong | Gale |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

| Direction |
|---|
| |

Water:

| Calm | Slight | Mod | Rough | V. Rough |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

Cloud Cover:

| Cloud % |
|---|
| |

Rainfall:

| Nil | Light | Mod | Heavy |
|---|---|---|---|
| 1 | 2 | 3 | 4 |

| Boat Launches | | | | Boat Retrievals | | | |
|---|---|---|---|---|---|---|---|
| Time | Type | Time | Type | Time | Type | Time | Type |
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| Total Number of Trailers | |
|---|---|
| At Start | At Finish |
| | |

Boat Types
P: Power boat
Y: Yacht
O: Other

## GASCOYNE RECREATIONAL FISHING SURVEY
## INTERVIEW QUESTIONNAIRE

**Date:** ________ **Boat Ramp:** ____________________ **Boat Reg. No.:** ______________

| Retrieve Time | Launch Time (include date if different) | Boat (Pwr/Yacht/Other) | Fishing (Yes/No) | Dive/sNorkel/W-Ski/Other | Number of Persons on Boat | Number Persons Fishing | Home Postcode of Interviewee | Length of Boat (ft/m) | Block Number | Time Spent Fishing (decimal hrs) | Number of Lines Used | Number and Type of Nets (Crab, Gill, Scoop, Pots) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
| | | | | | | | | | | FISHERS ONLY | | |

| Species (Also record sex for lobsters) | Number Kept | Number Released | Taken by Sharks | Number break-offs | Under/Over size Kept | Species Targeted 1 ____________ Species Targeted 2 ____________ Measurements (mm) |
|---|---|---|---|---|---|---|
| Blue - lined Emperor | | | | | | |
| Pink Snapper | | | | | | |
| Spangled Emperor | | | | | | |
| Chinaman Cod | | | | | | |
| Sweetlip Emperor | | | | | | |
| Western Butterfish | | | | | | |
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| | | | | | | |

2. What is the size limit for ____________ *targeted/predominant species from catch*?

| Correct | Incorrect | Donít Know |
|---|---|---|

3. What is the bag limit for ____________ *targeted/predominant species from catch*?

| Correct | Incorrect | Donít Know |
|---|---|---|

# Appendix 3. Catch curve analyses for spangled emperor stocks repeated for different 'year' data groupings to evaluate sensitivity of results to data inputs.

**Table A2.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the spangled emperor stocks for data grouped by commercial year (1 Sep 2006 – 31 Aug 2007). 'Upper' and 'Lower' refer to upper and lower bounds of bias-adjusted 95% confidence intervals. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise et al., 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level.

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **North Gascoyne; n = 270** | | | | | |
| Method I | | | | | |
| Upper | 0.522 | 0.351 | | | |
| Estimate | 0.374 | 0.146 | 0.228 | 1.562 | $F_{Limit}$ < ***F*** |
| Lower | 0.336 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.479 | 0.351 | | | |
| Estimate | 0.353 | 0.146 | 0.207 | 1.415 | $F_{Threshold}$ < ***F*** < $F_{Limit}$ |
| Lower | 0.282 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.421 | 0.351 | | | |
| Estimate | 0.273 | 0.146 | 0.127 | 0.873 | $F_{Target}$ < ***F*** < $F_{Threshold}$ |
| Lower | 0.225 | 0.023 | | | |
| **South Gascoyne; n = 201** | | | | | |
| Method I | | | | | |
| Upper | 0.332 | 0.351 | | | |
| Estimate | 0.218 | 0.146 | 0.072 | 0.493 | ***F*** < $F_{Target}$ |
| Lower | 0.149 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.164 | 0.351 | | | |
| Estimate | 0.143 | 0.146 | -0.003 | n/a | ***F*** < $F_{Target}$ |
| Lower | 0.104 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.1484 | 0.351 | | | |
| Estimate | 0.1482 | 0.146 | 0.004 | 0.028 | ***F*** < $F_{Target}$ |
| Lower | 0.146 | 0.023 | | | |

**Table A3.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the spangled emperor stocks for data grouped by calendar year (1 Jan – 31 Dec 2007). 'Upper' and 'Lower' refer to upper and lower bounds of bias-adjusted 95% confidence intervals. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise *et al*., 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level.

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **North Gascoyne; n = 334** | | | | | |
| Method I | | | | | |
| Upper | 0.485 | 0.351 | | | |
| Estimate | 0.376 | 0.146 | 0.230 | 1.573 | $F_{Limit} < \boldsymbol{F}$ |
| Lower | 0.329 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.392 | 0.351 | | | |
| Estimate | 0.338 | 0.146 | 0.192 | 1.312 | $F_{Threshold} < \boldsymbol{F} < F_{Limit}$ |
| Lower | 0.272 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.396 | 0.351 | | | |
| Estimate | 0.284 | 0.146 | 0.138 | 0.949 | $F_{Target} < \boldsymbol{F} < F_{Threshold}$ |
| Lower | 0.233 | 0.023 | | | |
| **South Gascoyne; n = 245** | | | | | |
| Method I | | | | | |
| Upper | 0.349 | 0.351 | | | |
| Estimate | 0.251 | 0.146 | 0.105 | 0.721 | $F_{Target} < \boldsymbol{F} < F_{Threshold}$ |
| Lower | 0.176 | 0.023 | | | |
| Method II | | | | | |
| Upper | 0.166 | 0.351 | | | |
| Estimate | 0.152 | 0.146 | 0.006 | 0.043 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.110 | 0.023 | | | |
| Method III | | | | | |
| Upper | 0.200 | 0.351 | | | |
| Estimate | 0.150 | 0.146 | 0.004 | 0.028 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.149 | 0.023 | | | |

# Appendix 4. Catch curve analyses for goldband snapper stocks repeated for different 'year' data groupings to evaluate sensitivity of results to data inputs.

**Table A4.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the goldband snapper stock for data grouped by calendar year (1 Jan – 31 Dec). 2006, 2007 data excluded due to low sample sizes. 'Upper', 'Lower' and 'Estimate' and refer to: (i) the upper and lower bounds of bias-adjusted 95% confidence intervals, and the deterministic estimate, for *Z*; and (ii) the upper end, lower end and median of the range estimated by Newman and Dunk (2003) for *M*. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise *et al*., 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level.

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **2005; n = 262** | | | | | |
| Method I | | | | | |
| Upper | 0.339 | 0.139 | | | |
| Estimate | 0.147 | 0.121 | 0.026 | 0.216 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.098 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.145 | 0.139 | | | |
| Estimate | 0.122 | 0.121 | 0.001 | 0.006 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.094 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.409 | 0.139 | | | |
| Estimate | 0.151 | 0.121 | 0.029 | 0.243 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.136 | 0.104 | | | |
| **2008; n = 310** | | | | | |
| Method I | | | | | |
| Upper | 0.248 | 0.139 | | | |
| Estimate | 0.155 | 0.121 | 0.034 | 0.278 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.111 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.182 | 0.139 | | | |
| Estimate | 0.161 | 0.121 | 0.040 | 0.327 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.132 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.176 | 0.139 | | | |
| Estimate | 0.141 | 0.121 | 0.020 | 0.166 | $\boldsymbol{F} < F_{Target}$ |
| Lower | 0.124 | 0.104 | | | |

**Table A5.** Estimates of *Z, M,* and the deterministic ratios of *F* (= *Z* – *M*) to *M* as a performance indicator for the goldband snapper stock for data grouped by recreational year (1 Apr – 31 Mar). 2006/07 data excluded due to low sample size. 'Upper', 'Lower' and 'Estimate' and refer to: (i) the upper and lower bounds of bias-adjusted 95% confidence intervals, and the deterministic estimate, for *Z*; and (ii) the upper end, lower end and median of the range estimated by Newman and Dunk (2003) for *M*. Reference levels: $F_{Target}$ = 2/3 *M*; $F_{Threshold}$ = *M*; $F_{Limit}$ = 1.5 *M* (Wise *et al*., 2007), where management objective is to keep *F* to less than the $F_{Threshold}$. Cells are coloured to indicate uncertainty for the catch curve estimates (i.e., *Z* only, ignoring uncertainty in *M*), in relation to corresponding reference levels for management, i.e.: (i) Exceeds Limit level; (ii) Between Limit & Threshold level; (iii) Between Threshold & Target level; (iv) Lower than Target level.

| | *Z* | *M* | *F* | *F: M* | Reference level |
|---|---|---|---|---|---|
| **2005/06; n = 307** | | | | | |
| Method I | | | | | |
| Upper | 0.337 | 0.139 | | | |
| Estimate | 0.146 | 0.121 | 0.025 | 0.204 | ***F*** < $F_{Target}$ |
| Lower | 0.111 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.143 | 0.139 | | | |
| Estimate | 0.134 | 0.121 | 0.013 | 0.106 | ***F*** < $F_{Target}$ |
| Lower | 0.109 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.226 | 0.139 | | | |
| Estimate | 0.161 | 0.121 | 0.039 | 0.324 | ***F*** < $F_{Target}$ |
| Lower | 0.148 | 0.104 | | | |
| **2007/08; n = 313** | | | | | |
| Method I | | | | | |
| Upper | 0.249 | 0.139 | | | |
| Estimate | 0.168 | 0.121 | 0.046 | 0.383 | ***F*** < $F_{Target}$ |
| Lower | 0.110 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.202 | 0.139 | | | |
| Estimate | 0.167 | 0.121 | 0.046 | 0.379 | ***F*** < $F_{Target}$ |
| Lower | 0.135 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.204 | 0.139 | | | |
| Estimate | 0.161 | 0.121 | 0.040 | 0.330 | ***F*** < $F_{Target}$ |
| Lower | 0.095 | 0.104 | | | |
| **2008/09; n = 220** | | | | | |
| Method I | | | | | |
| Upper | 0.395 | 0.139 | | | |
| Estimate | 0.132 | 0.121 | 0.011 | 0.092 | ***F*** < $F_{Target}$ |
| Lower | 0.090 | 0.104 | | | |
| Method II | | | | | |
| Upper | 0.161 | 0.139 | | | |
| Estimate | 0.139 | 0.121 | 0.017 | 0.143 | ***F*** < $F_{Target}$ |
| Lower | 0.109 | 0.104 | | | |
| Method III | | | | | |
| Upper | 0.188 | 0.139 | | | |
| Estimate | 0.128 | 0.121 | 0.007 | 0.057 | ***F*** < $F_{Target}$ |
| Lower | 0.123 | 0.104 | | | |

# Appendix 5. Supplementary analysis of spangled emperor catch rate data

***Methods: standardisation for the effects of vessel and season***

1. Generalized linear (GLM) and generalized linear mixed effects (GLMM) models were used to account for the influence of season (Summer, Autumn, Winter, Spring) and vessel on catch rates (CPUE) of spangled emperor from logbook returns submitted by commercial line fishers to the Department. These models were fitted to CPUE only for records when spangled emperor were caught and therefore resulting standardised CPUE trends should be treated with caution. The use of a CPUE standardisation method that utilises data for this type of fishing when spangled emperor were not caught (e.g., the "delta" method; Lo et al., 1992) is an important component of CPUE standardisation and is an area for future study. The current analysis assumes that any such effect(s) are negligible.

2. For the North Gascoyne, only trends in CPUE for the coastal 60 x 60 nm block 22130 was analysed because blocks to its north represented the separately managed Pilbara line, trap and trawl fisheries from 1992 onwards.

3. For the South Gascoyne, trends in CPUE were analysed for non-boundary blocks only. Since an inspection of available data per block and year revealed sample zeros for one block (24120) prior to 1984/85, records prior to 1984/85 were omitted, to reduce the influence of potential hyperstability on resulting trends (Walters, 2003). This was preferred to the generation of CPUE from interpolation or extrapolation methods for replacing the sample zeros because it avoided allocation of generated CPUE among vessels or months. Data for some blocks that had changed name over time but overlapped the same location were aggregated together.

4. Prior to the fitting of GLM and GLMMs, CPUE was calculated for all records (kg $blockday^{-1}$) for handline fishing methods only (see Section 6.2). A natural-logarithmic transformation was applied to these CPUE to improve normality and to make the model terms additive (Hilborn and Walters 1992).

5. As there were relatively few records of CPUE data available for each vessel per year (Block 22130: mean = $3.9 \pm 0.3$; South Gascoyne blocks: mean = $5.7 \pm 0.7$), only a few key factors were incorporated as fixed (year, season) and random (vessel) factors in the standardisations. All models included a year term, as this was required to extract annual standardised CPUE by multiplying the geometric mean of the base vessel in the first year by back-transformed year coefficients estimated by the model (Maunder and Punt 2004). The simplest model was a GLM with the single treatment variable of year. GLMMs were fitted using the penalised quasi-likelihood algorithm of Schall (1991) to include the random vessel term for explaining ln(CPUE). The highest order model was a GLMM including all three treatment variables. All were of the Gaussian family and had identity link functions.

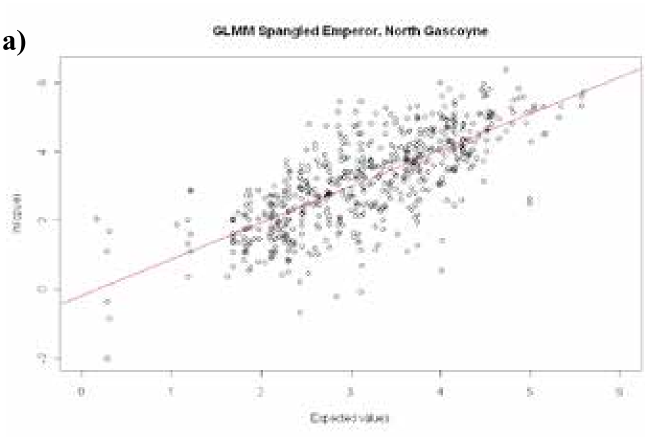
***Results & Discussion***

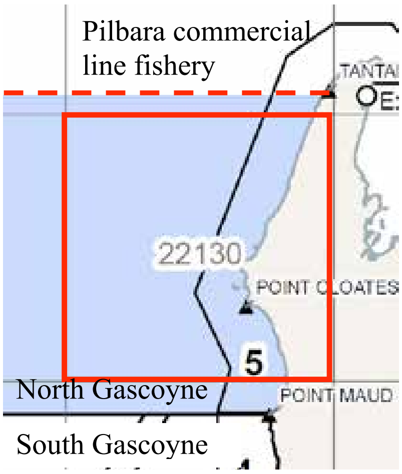
The simplest (GLM) standardisation for the single effect of year is an improvement over nominal trends in CPUE presented in Section 6.2 in principle because, in effect, these trends represent geometric means of annual CPUE across all monthly logbook reporting records, which is preferable to the method of simply dividing total catch by total effort (Walters 2003). Nevertheless, the displayed trends for single factor GLMs generally reflect patterns of nominal CPUE and catches shown in Figure 6.2.4. Vessel is shown to have an important influence on

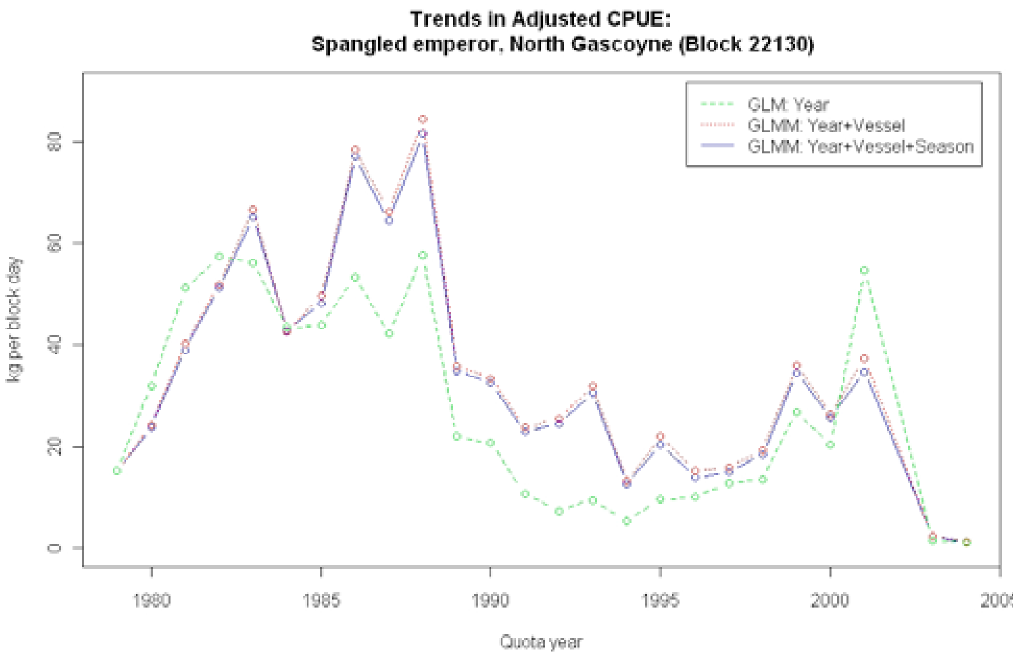
CPUE, in that the greatest shift in pattern was observed when this term was added, and a negligible change when season was added, to the GLMMs fitted to both datasets (Fig. A1).

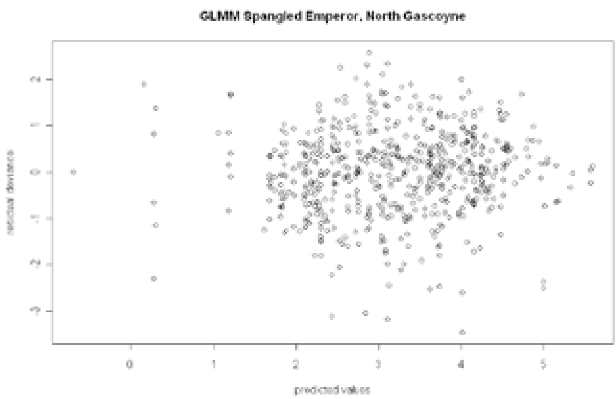
The vessel term accounted for much variance in ln(CPUE) for the North Gascoyne (Block 22130) dataset, and had a standard deviation ($\hat{\sigma}_V$) of 0.76, compared to a residual standard deviation ($\hat{\sigma}_\varepsilon$) of 0.93. Vessel resulted in an elevated CPUE from 1986/87 to 1995/96, possibly reflecting changing fleet dynamics over that period and corresponding differences in the fishing power of different vessels for catching spangled emperor in that area (see Section 6.1). The vessel term also seemed to have an important influence on standardised CPUE in the South Gascoyne, lowering the values notably from 1986/87 to 1994/95 ($\hat{\sigma}_V$=0.55, $\hat{\sigma}_\varepsilon$ = 1.09). Declines in nominal CPUE from the late 1980s to mid 1990s for the North and from 1991/92 to 2000/01 for the South in Section 6.2 were corroborated for these results, suggesting that these declines were not likely attributable to changes/differences in fishing power for catching spangled emperor among different vessels over this period, but to some other unknown factor(s). The limited spatiotemporal resolution of these data (i.e., monthly, 60 x 60 nautical mile blocks) precludes further exploration of such effects.

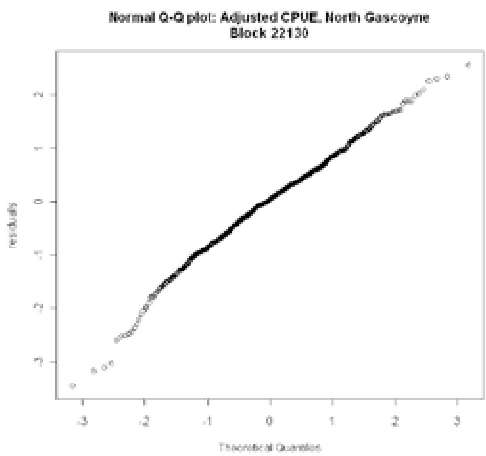
a)


GLMM Spangled Emperor, North Gascoyne
Expected values


Pilbara commercial line fishery
22130
POINT CLOATES
5
North Gascoyne
POINT MAUD
South Gascoyne


Trends in Adjusted CPUE:
Spangled emperor, North Gascoyne (Block 22130)
GLM: Year
GLMM: Year+Vessel
GLMM: Year+Vessel+Season
kg per block day
Quota year


GLMM Spangled Emperor, North Gascoyne
predicted values


Normal Q-Q plot: Adjusted CPUE, North Gascoyne
Block 22130
residuals
Theoretical Quantiles

b)

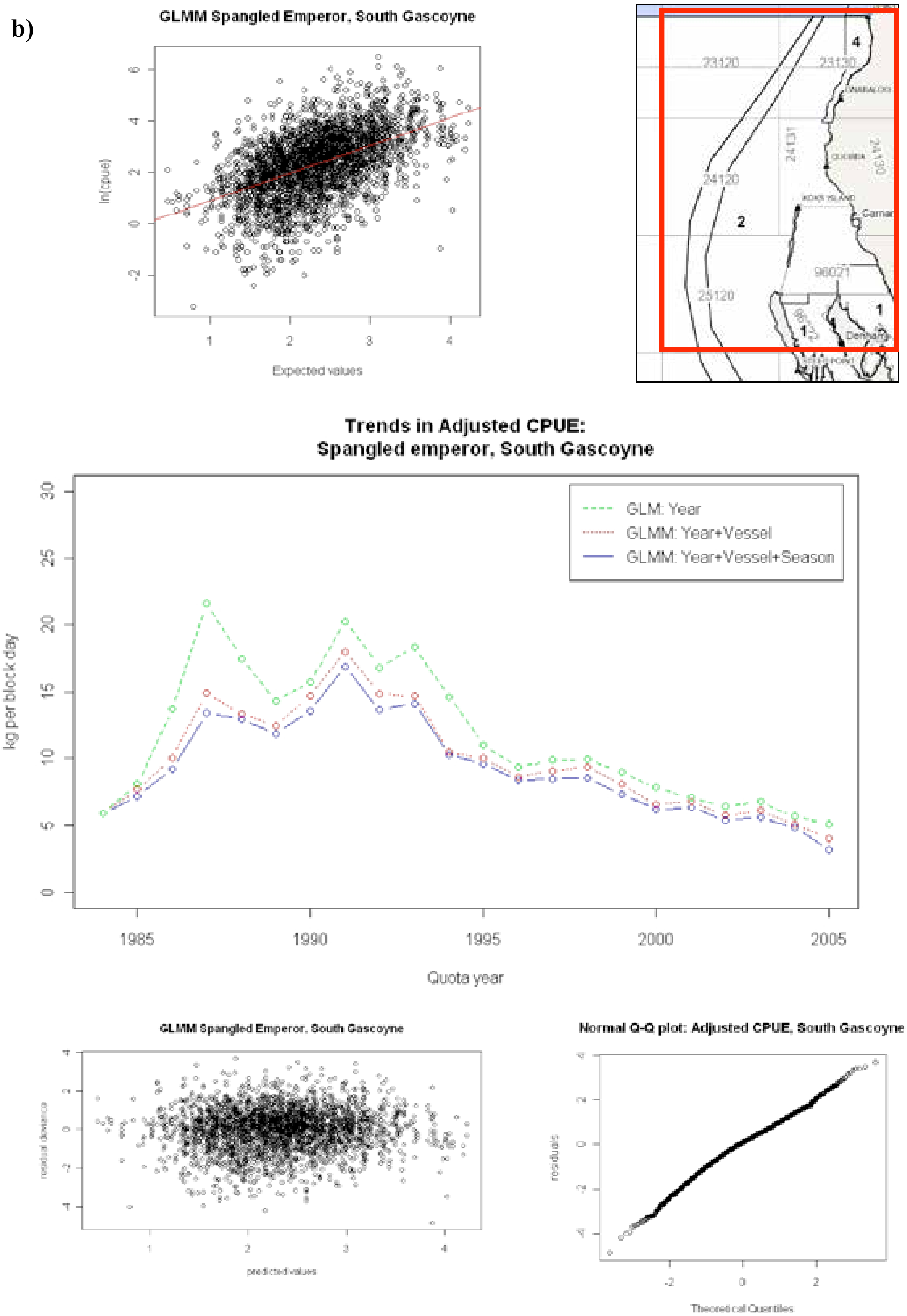



**Figure A1.** Commercial catch rate data for spangled emperor, adjusted for the effect of vessel (random) and season (fixed) using a Generalised Linear Mixed Effects Model (GLMM) over time (Commercial years: 1 Sep – 31 Aug) for (a) North Gascoyne and (b) South Gascoyne (see Methods). Red squares group spatial blocks from which CPUE data were analysed (inset).

### *References: Appendix 5*

Hilborn, R. & Walters, C.J. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York.

Lo, N.C, Jacobsen, L.D. & Squire, J.L. (1992). Indices of relative abundance for fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences,* 49, 2515-2526.

Maunder, M.N. & Punt, A.E. (2004). Standardising catch and effort data: a review of recent approaches. *Fisheries Research* 70, 141-159.

Schall, R. (1991). Estimation in generalised linear models with random effects. *Biometrika* 78, 719-727.

Walters, C. (2003). Folly and fantasy in the analysis of spatial catch rate data. *Canadian Journal of Fisheries and Aquatic Sciences* 60, 1433-1436.

# Appendix 6. Vulnerability attributes

**Table A6.** Attributes indicating vulnerability of stock(s) of indicator species.

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

| Attribute | Type | Low | Medium | High | Reference* |
|---|---|---|---|---|---|
| Recruitment variability | Productivity | Regular, or consistent recruitment that is predictable on an annual basis<br>e.g., annual variation within ~ 20% | Average recruitment is consistent but variable among years over short time periods<br>e.g., annual variation of ~ 50% within an average 3 year period | Infrequent, highly variable recruitment over time that cannot be predicted<br>e.g., annual range 0-100%, | 1, 3 |
| Breeding strategy and dispersal of eggs/larvae | Productivity | Propagules widely dispersed during pelagic phase or juvenile stage<br>e.g., broadcast spawner with wide dispersal (100s of kms). | Propagules have limited dispersed capacity during pelagic phase or juvenile stage<br>e.g., broadcast spawner with limited dispersal (10s of kms). | Restricted dispersal of eggs, larvae, juveniles<br>e.g., demersal egg layer or live bearer | 1, 3 |
| Distribution and movement of adults | Susceptibility | Widespread distribution, and/or highly mobile<br>e.g., capacity to move 100s of kms along coastline | Limited distribution, and/or limited mobility<br>e.g., adults move 10s of kms along coastline | Restricted/endemic and/or sedentary (longshore movement restricted), possibly inshore-offshore movements only<br>e.g., adult home range < 10km | 1 |
| Post-capture mortality | Susceptibility | Generally high survivorship post-capture. Large amount of evidence of post-capture release and survival.<br>e.g., probability of survival > 67% | Survivorship largely dependent on capture method and depth of capture. Intermediate levels of post-capture survival.<br>e.g., probability of survival 33 - 67% | Majority dead or in poor health/ showing signs of barotrauma when released, regardless of depth of capture or capture method.<br>e.g., probability of survival < 33% | 2 |
| Resilience to other sources of mortality | Productivity | Highly adaptable to variable environments and/or environments/habitats are healthy and in an optimum condition | Moderate levels of resilience, and/or environments/habitats are not in an optimum condition but are recovering | Limited adaptability to change and/or environments/habitats are degraded and/or under threat | 1 |
| Level of Uncertainty | | Most attributes known<br>e.g., 0 - 3 unknown | Some attributes known<br>e.g., 4 - 8 unknown. | Few attributes known<br>e.g., 9 - 12 unknown | |
| Overall Productivity | | Most productivity attributes are low | Most productivity attributes are medium | Most productivity attributes are high | |
| Overall Susceptibility | | Most susceptibility attributes are low | Most susceptibility attributes are medium | Most susceptibility attributes are high | |

* Reference: Examples for vulnerability criteria consistent with reference levels developed in the following publications: 1 = Wise et al. (2007); 2 = Patrick et al. (2010); 3 = Hobday et al. (2011); 4 = DoF (2011)*.

* DoF. 2011. Resource Assessment Framework (RAF) for Finfish Resources in Western Australia. Fisheries Occasional Publication. No. 85. Department of Fisheries, Western Australia. 24 pages. www.

** Trophic level scores can be obtained from FishBase (Froese and Pauly 2011)*

*** Example cut-off scores derived by rounding up the cut-off scores from Patrick *et al.* (2010) and Hobday *et al.* (2011) to the nearest whole integer. This seems to be appropriate for demersal scalefish indicator species, because targeted species will have higher trophic status than the broader range of species categorised for Ecological Risk Assessments.

**** Example levels of availability consistent with those in Patrick *et al.* (2010). Example selectivity levels for medium and high vulnerability categories consistent with convention that the MLL is often set at the approximate length at mean maturity. $t_c$ = mean age at first capture; $t_{mat}$ = mean age at first maturity.

(Footnotes)

1 Reference levels for *F*: $F_{target} = (2*M)/3$; $F_{threshold} = M$; $F_{limit} = 1.5*M$

2 Reference levels for *B*: $B_{target} = 0.4*B_{virgin}$; $B_{threshold} = 0.3*B_{virgin}$; $B_{limit} = 0.2*B_{virgin}$

fish.wa.gov.au/docs/op/op085/index.php?0706.

* Froese, R. and D. Pauly (Eds.) 2011. Fishbase. World Wide Web electronic publication www.fishbase.org, version (08/2011).