Fisheries biology and management of pink snapper, *Pagrus auratus*, in the inner gulfs of Shark Bay, Western Australia

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Declaration

I declare that the information contained in this thesis is the result of my own research, unless stated otherwise, and contains as its main content, research that has not previously been submitted for a degree at any other tertiary institution.

Gary Jackson

December 2007
‘Snapper fishing in Shark Bay’ by Ellie Jackson, 12 years
Abstract

This study explored an important aspect of the basis for the highly complex population structure of pink snapper (*Pagrus auratus*) within the inner gulfs of Shark Bay, investigated how growth and reproduction differ among these closely-adjacent but separate stocks, and obtained biomass estimates for each stock that are essential for the sustainable management of the regionally-important recreational pink snapper fishery. Using ichthyoplankton data in combination with hydrodynamic modelling, *P. auratus* eggs and larvae were shown to be retained within localized meso-scale eddies that were coincident with the main inner gulf spawning areas. Such hydrodynamic retention, in conjunction with tagging and otolith chemistry data that indicates very limited movement of juvenile and adult fish, explains how separate pink snapper populations can exist in the adjacent waters of the Eastern Gulf, Denham Sound and Freycinet Estuary. The study found significant variation in maximum age, growth, maturity and spawning time at fine spatial scales. Such variation, unusual for a large, potentially mobile fish inhabiting a marine environment with no obvious physical barriers, is linked to the inner gulfs’ marked environmental heterogeneity, the low levels of mixing and historic differences in fishing pressure among the three areas. The daily egg production method (DEPM) was used, for the first time with this species in Western Australia, to provide estimates of spawning biomass of the three separate inner gulf *P. auratus* stocks. While relatively imprecise, mostly due to imprecision in estimation of daily egg production, these estimates demonstrated that these stocks are very small (measured in tens of tonnes) compared with *P. auratus* stocks elsewhere in Australia and New Zealand. Biological data and DEPM estimates obtained from this study were incorporated in age-based stock assessment models that have been used to determine the status of inner gulf pink snapper stocks since 2002.
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Acknowledgements

As I was preparing to write this, a colleague made a comment about ‘remember just how far you have come’. Well, cliché or not, it has been a long, long journey. Never, when I first graduated from Plymouth Polytechnic back in 1980, or 20 or so years ago when working as carpenter/cabinet maker in the UK, did I imagine I would even think about doing a PhD. Anyway, here I am, and as I’m writing this, with the end really in sight, I’m starting to have some fun.

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Having finally finished this thesis, I am starting to look forward to new challenges, and hope that I can continue to repay the faith that some people have had in me over this part of the journey.
Overview of thesis

Pink snapper, *Pagrus auratus*, have been the basis of an important recreational fishery in the inner gulfs of Shark Bay since the 1970s at least. Robust information on the biology and population dynamics of *P. auratus* inside Shark Bay was lacking in 1996-1997 when such information was urgently required by fisheries managers to support proposed drastic management action to protect spawning stocks in the Eastern Gulf. This situation prompted comprehensive research on *P. auratus* in all the main fishing areas in the inner gulfs of Shark Bay that commenced in 1998, much of which forms the basis of this study. The principal objectives were to (i) investigate *P. auratus* stock structure further and, specifically, to test the hypothesis that hydrodynamic conditions in the inner gulfs restrict dispersal of *P. auratus* eggs and larvae among the main spawning areas, (ii) test the hypothesis that key biological characteristics might vary at fine spatial scales given the complexity of *P. auratus* population structure in the region, the Bay’s strong environmental gradients and historic differences in fishing pressure, and (iii) provide estimates of *P. auratus* stock biomass and investigate how the respective fishable stocks had responded to exploitation and management through the use, for the first time for this species in Western Australia, of the daily egg production method (DEPM) as a stock assessment tool.

Ichthyoplankton data collected between 1997-2000 and hydrodynamic modelling were used in combination to investigate the dispersal of *P. auratus* eggs and larvae from the main inner gulf spawning areas. Hydrodynamic conditions during the austral winter saw the pelagic eggs and larvae retained within localized meso-scale eddies that were coincident with these locations. Results indicated no spatial
connectivity between the main *P. auratus* spawning areas with the exception of the spawning grounds in northern Denham Sound and oceanic waters in the Naturaliste Channel. Hydrodynamic retention therefore provides a mechanism that, in conjunction with tagging data that indicates very limited movement of juvenile and adult fish, explains how separate *P. auratus* populations can exist in such close proximity in the inner gulfs.

Samples of *P. auratus* obtained from the Eastern Gulf, Denham Sound and Freycinet Estuary via fishery-dependent and independent methods were used to investigate spatial variation in life history characteristics. Spawning occurred from late autumn through to mid-spring; fish in the Eastern Gulf and Denham Sound mostly spawned in May-July compared with August-October in the Freycinet Estuary. The longer spawning season in the Freycinet Estuary (~5-6 months) likely represents a risk-spreading strategy presumably to ensure survival of eggs and larvae in the more extreme (salinity ~40-50+) and variable conditions (annual water temperature range ~12-13 °C). Females reach 50% maturity at the smallest size (348 mm FL) and youngest age (3.2 years) in the Eastern Gulf compared with Denham Sound (401 mm FL, 5.5 years) and Freycinet Estuary (420 mm FL, 4.5 years). Batch fecundity is higher for larger females; a fish of 500 mm FL produces ~100,000 eggs per spawning event compared to ~350,000 by a fish of 700 mm FL. *P. auratus* from inner Shark Bay form a single opaque zone in their sagittal otoliths each year with most fish completing their opaque zones in August-November. Opaque zone counts, in combination with month of capture, birth date and increment growth at the otolith edge, can be used to age *P. auratus* from inner Shark Bay. Maximum age observed was 31 years in the Freycinet Estuary, 19 years in Denham Sound and 17 years in the Eastern Gulf. Three-parameter
von Bertalanffy growth models fitted the length-at-age data reasonably well. Growth coefficients were higher in the Eastern Gulf \((K, 0.18 \text{ and } 0.17 \text{ year}^{-1}, \text{ females and males, respectively})\) and Freycinet Estuary \((0.17 \text{ year}^{-1} \text{ both sexes})\) compared with Denham Sound \((0.14 \text{ and } 0.18 \text{ year}^{-1}, \text{ respectively})\). Older fish \((i.e. \text{ 15 years or more})\) were more prevalent in samples from the Freycinet Estuary where fish of up to 25 years of age were consistently observed in recreational catches up to 2004. Using length-at-age data collected during a 5-year fishing moratorium, natural mortality, \(M\), was directly estimated at 0.22 \((95\% \text{ C.I. 0.09-0.34}) \text{ year}^{-1}\) in the Eastern Gulf, significantly higher than the base case value of 0.075 year\(^{-1}\) that is used in \(P.\ auratus\) stock assessments in New Zealand.

DEPM ichthyoplankton surveys and sampling of spawning fish were undertaken concurrently during the peak spawning period in each area between 1998-2004. Spawning occurs mostly between mid-afternoon and mid-evening. Large aggregations of spawning fish were observed in the Eastern Gulf and Denham Sound but not in Freycinet Estuary, where fish appear to typically spawn in much smaller groups. There was a strong relationship between lunar cycle and spawning with spawning activity greatest around the new moon and, to a lesser extent, around full moon. The spawning biomasses of \(P.\ auratus\) stocks in the inner gulfs are very small \((\text{measured in tens of tonnes})\). The DEPM is a viable assessment tool for \(P.\ auratus\) in inner Shark Bay. A more intensive sampling regime within a stratified-systematic design is recommended for future DEPM ichthyoplankton surveys.

Based on information provided by this study \((\text{egg and larval dispersal, variation in life history characteristics})\) and associated stock identification research \((\text{tagging,}


otolith stable isotopes), in conjunction with existing information (genetics, tagging, otolith chemistry), separation between spawning populations in Denham Sound and the Freycinet Estuary was acknowledged with recognition of three discrete inner gulf \textit{P. auratus} stocks, \textit{i.e.} Eastern Gulf, Denham Sound and Freycinet Estuary, in 2000. Biological data for each stock from this study were incorporated into age-based stock assessment models for the first time in 2002; results of these assessments were used, in consultations with stakeholders, to consider a range of management options for the inner gulf snapper fishery for 2003 and onwards. Future research should include: monitoring of recreational \textit{P. auratus} catches and overall fishing effort; further investigation into how the respective populations respond following high levels of exploitation; determination of the extent to which annual recruitment strength varies between the three areas; and refinement of the genetic relationship between local \textit{P. auratus} using a DNA-based approach.