Stock structure of a coral reef fish, *Plectropomus leopardus*: identification and implications for harvest strategy evaluation

PhD thesis submitted by

Mikaela Annika Johansdotter Bergenius BSc(Hons)

in March 2007

For the degree of Doctor of Philosophy
School of Marine Biology and Aquaculture
James Cook University
Australia

STATEMENT OF ACCESS

I, the undersigned, the author of this thesis, understand that James Cook University will make this thesis available for use within the University Library and, via the Australian Digital Thesis network, for use elsewhere.

I understand that, as an unpublished work, a thesis has significant protection under the Copyright Act and I do not wish to place any further restriction on access to this work.

________________________ __________________

Mikaela A J Bergenius Date

STATEMENT OF SOURCES

DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

Mikaela A J Bergenius

Date

STATEMENT OF CONTRIBUTION OF OTHERS

This thesis includes some collaborative work with my supervisors Dr Gavin Begg, Prof. Bruce Mapstone, Prof. Garry Russ and Dr Rich Little, as well as with Dr Dong C. Lou, Mr Cameron Murchie and Dr André Punt. For all the project components in this thesis I was responsible for the concept and aims, carrying out the laboratory work, the statistical analysis, results interpretation and synthesis, and the writing of all text in the thesis and publications. My supervisors assisted with their advice on these issues, with their contributions reflected by the order of the co-authors for each paper. Rich Little (CSIRO) also assisted with the coding of ELFSim for the purpose of this project. CSIRO Marine and Atmospheric Research assisted with in-kind contribution during a one month stay at the laboratory in Hobart. André Punt assisted with technical and editorial advice for the ELFSim paper. Gavin Begg and Bruce Mapstone also assisted financially towards the Otolith Chemistry paper and with in-kind contributions for the production of this thesis. The samples from which this thesis was derived were provided by Bruce Mapstone and others from the Effects of Line Fishing Experiment done over 11 years on the Great Barrier Reef. Dong C. Lou aged most of the *P. leopardus* samples used in this thesis and assisted with minor editorial advice on the Life History paper. Cameron Murchie assisted with some of the laboratory work for the Otolith Chemistry paper. CRC Reef assisted with financial support towards my stipend, research funds and conference travel support. The School of Marine Biology and Aquaculture assisted with in-kind contribution, research funds and conference travel support. The Great Barrier Reef Marine Park Authority assisted with research funds towards the Otolith Chemistry analysis.

List of papers:

Chapter 2:

Bergenius MAJ, Mapstone BD, Begg GA, Murchie CD. 2004. The use of otolith chemistry to determine stock structure of three epinepheline serranid coral reef fishes on the Great Barrier Reef, Australia. Fisheries Research. 72:253-270.

Chapter 3:

Bergenius MAJ, Mapstone BD, Begg GA. 2006. The use of otolith morphology to indicate stock structure of common coral trout *Plectropomus leopardus*, on the Great Barrier Reef, Australia. Fishery Bulletin. 104(4):498-511.

Chapter 4:

Bergenius MAJ, Mapstone BD, Begg GA, Lou DC, Russ G. The use of vital life history characteristics for the identification of appropriate management units of coral trout, *Plectropomus leopardus*, on the Great Barrier Reef, Australia. Can. J. Fish. Aquat.Sci. In Review.

Chapter 5:

Bergenius MAJ, Mapstone BD, Little, RA, Begg GA, Punt AE. Harvest impacts on spawning biomass of common coral trout, *Plectropomus leopardus,* in the face of spatially variable life history characteristics. *To be submitted after finishing thesis.*

ACKNOWLEDGEMENTS

There are a many people that have contributed towards the completion of this PhD thesis. Particularly, I would like to thank:

- Bruce Mapstone for your guidance, wisdom, insight and patience throughout my candidature and time with the Fishing and Fisheries Team. I could not have completed this thesis without you and I feel very fortunate to have had the opportunity to learn from you.
- Gavin Begg for your extensive knowledge, enthusiasm and encouragement. Thank you also for all the personal support you have given me throughout my candidature.
- Garry Russ for interesting discussions and testing comments to the thesis and manuscript drafts.
- Rich Little for invaluable help with the modelling Chapter of this thesis. You have been very patient with me at times which I'm sure would really have been very frustrating….
- Ashley Williams for much support, advice and encouragement. I really appreciate all the times you have put your other work aside to offer helpful and idea forming discussions.
- All the other members of the Fishing and Fisheries Team: Aaron Ballagh, Sara Busilacchi, Carla Chen, Leanne Currey, Lou Dongchun, Barry Goldman, Annabel Jones, Amos Mapleston, Ross Marriott, Geoffrey Muldoon, Cameron Murchie, Rachel Pears, Ann Penny, Amy Smith, Iesha Stewart, Steve Sutton, Andrew and Renae Tobin, Dave Welch, Merome Wright.
- Andre Punt for prompt and insightful comments on the modelling Chapter.
- Simon Robertson for enthusiastic guidance with the Fourier analysis.
- Barry Goldman for impressive map-making skills.
- Jake Kritzer for early discussions on thesis ideas.
- Ken Anthony, Sula Blake, Jens Bjelvenmark, Karin Buechler, Malena Granbom, Bridget Green, Selma Klanten, Rachel Pears, Marie-Lise Schlappy, Rebecka

Teper, Renae Tobin and Dave Welch for your friendship, general advice and encouragement.

- Yonna and Stuart Pettigrew, Amelie and Richard Alte, Mum Birgitta Bergenius and Dad Johan Bergenius for much listening and endless caring.
- Most importantly; Sebastien for not jumping off my PhD rollercoaster, but instead patiently riding it with me, holding my hand, and steering it back onto track the many times it was close to derailing. Thank you for everything.
- CRC Reef for financial support towards my stipend, research funds and conference travel support.
- The Fishing and Fisheries Project for in-kind and logistic support, as well as funding towards the Otolith Chemistry analysis.
- The School of Marine Biology and Aquaculture for in-kind contribution, research funds and conference travel support.
- The Great Barrier Reef Marine Park Authority for research funds towards the Otolith Chemistry analysis.

ABSTRACT

The recognition of stocks, or spatially separate groups of individuals with persistent differences in biological characteristics, is important for the sustainable and optimised use of fisheries resources. Stocks with different biological characteristics may respond differently to harvest and therefore have different vulnerabilities to over-exploitation. Recent research suggests that spatial variation in biological characteristics at a range of scales is a feature of many coral reef fishes. An investigation of the temporal stability of spatial differences and the identification of stocks that may require separate management strategies, however, has rarely been undertaken for such fish. Moreover, little is known about the implications of spatial differences in biological characteristics for spatially separate components as well as entire populations of coral reef fishes when subject to various levels of harvest.

This thesis has four primary aims: 1) to investigate the use of otolith chemistry as an indirect indicator of stock structure of three exploited epinepheline serranid coral reef fishes, *Plectropomus leopardus*, *Cephalopholis cyanostigma* and *Epinephelus fasciatus*, on the Great Barrier Reef (GBR), Australia; 2) to investigate the use of otolith morphology as an indirect indicator of stock structure of *P. leopardus*; 3) to investigate the spatial and temporal patterns in life history characteristics of *P. leopardus* as direct manifestations of stock structure; and 4) to examine the implications of spatial variability in life history characteristics of *P. leopardus* for harvest strategy evaluation.

The first two aims were achieved by comparing otolith chemistry (Mn, Sr, Ba) and otolith morphology (otolith length, width, area, perimeter, circularity, rectangularity and Fourier Harmonics) variables among four regions of the GBR,

separated by 100s of kilometres, as well as among three reefs 100s – 1000s of meters apart within each region. The temporal stability in otolith chemistry and morphology signals was also examined by comparing two cohorts of *P. leopardus* and individuals of *C. cyanostigma* and *E. fasciatus* from the same cohorts that were collected two years before and two years after a significant weather disturbance (Tropical Cyclone Justin) in March 1997. Persistent differences in otolith chemistry were found at both broad and fine spatial scales, and differences in otolith morphology were seen at mainly broad spatial scales. Moreover, some aspects of chemical and morphological signals differed between cohorts and individuals collected before and after the Cyclone. The results highlight the need to incorporate data from several years in studies using these techniques to discriminate temporary and possibly misleading signals from those that indicate persistent spatial structure in stocks. These results provide a good starting point for future research on groups of individuals that have lived at least part of their lives in different environments and therefore may have different biological characteristics, although otolith chemistry and morphology should not be used in isolation to determine stock structure.

The third aim was achieved by comparing vital life history characteristics of *P. leopardus* at the same broad regional and finer reef scale as the otolith chemistry and morphology. Temporal stability in stock structure was examined by comparing biological parameters among five consecutive years, from 1995 to 1999. The results matched the patterns indicated by otolith chemistry and morphology and emphasised that the stock structure of *P. leopardus* is far more complex than assumed previously. Mortality, growth, age richness and longevity of *P. leopardus* varied among reefs within regions and some estimates of growth and longevity also varied at the larger regional spatial scale. Several of the spatial patterns in these biological parameters

were complicated by inter-annual variation. Similar to the use of otolith chemistry and morphology, the life history results emphasised the importance of a multi-scaled sampling design, including a temporal component, when using biological characteristics to investigate the stock structure of tropical reef fishes. I proposed a theoretical model for conceptualising the stock identification and management challenge for *P. leopardus* that may be composed of a complex network of reef subpopulations, groups of subpopulations (i.e., regions), and potential stocks with persistent differences in biology.

The fourth aim was achieved using a spatially-structured management strategy evaluation model developed for *P. leopardus* harvested by the GBR line fishery. Relative spawning biomass of the population was estimated from simulations of four hypothetical scenarios of spatial variation in life history characteristics under each of five hypothetical effort scenarios. The life history scenarios involved simulating the *P. leopardus* population with or without differences in a) individual growth and b) mortality rates among four regions of the GBR. The different effort scenarios involved shifting fishing effort among the four regions. The effects of regional closures (no effort) were also examined. Trajectories of mean relative spawning biomass were compared among the different combinations of spatial and effort scenarios. Relative mean spawning biomass trajectories were also compared between two analytical approaches involving aggregating results over regions, as is usually done in fisheries assessments, or treating results separately for each region. The latter comparison directly assessed the impacts of erroneously assuming an homogeneous stock despite regional variation in life history parameters.

Including spatial variation in growth and mortality resulted in greater depletions of relative spawning biomass and longer times to recover relative to preexploitation levels for the population as a whole, as well as for several regions. Aggregating results across regions masked important region-specific patterns in the relative spawning biomass trajectories arising from spatial variation in biology, and so resulted in the wrong conclusions about whether particular management objectives were likely to be realised. These results suggest that spatial variation in growth, in particular, mortality and potentially other life history characteristics should be incorporated in future harvest strategy evaluations for *P. leopardus*. Further, the results suggest that the single management unit currently in place for *P. leopardus* on the GBR may need to be divided into finer spatial units to closer reflect biological stock units to deliver prudent biologically optimal harvests.

The results clearly have some important implications for the management and harvest of *P. leopardus* on the GBR. *P. leopardus,* and probably many other exploited coral reef fishes, should not be viewed or managed as single homogenous populations. Instead these populations should be considered as complex networks of spatially and temporally varying components which although interlinked, may require separate management strategies to assure their long-term sustainability and optimal harvest.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES