Estimating dispersal and population connectivity for temperate reef fishes at multiple spatial scales

Thesis submitted by

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BSc (Hons) The University of Sydney, Australia

October 2007

For the degree of Doctor of Philosophy

in Marine Biology

within the School of Marine & Tropical Biology

James Cook University

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Statement on the Contribution of Others and Declaration on Ethics

Drafts of the thesis were revised by Mike Kingsford, Tim Glasby, Michael Gillings, Heather Patterson, and Vanessa Miller-Sims. Development of microsatellite markers and resulting publications (Curley & Gillings 2004, Curley & Gillings 2006) resulted from collaborations with Michael Gillings at Macquarie University who provided technical expertise, support with laboratory work, and assisted with final interpretation and writing up of results.

Financial support during my PhD was provided by an Australian Post-graduate Award, a scholarship from the School of Marine and Tropical Biology, and a James Cook University Doctoral Completion Award. Research was funded by an Internal Research Award (JCU), NSW Fisheries Recreational Fishing Trust Grant (B. G. Curley), James Cook University Merit Research Grant (M. Kingsford), and a Macquarie University Research Development Grant (M. Gillings).

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the *National statement on Ethics Conduct in Research Involving Humans* (1999), the *Joint NHMRC/AVCC Statement and Guidelines on Research Practice* (1997), the *James Cook University Policy on Experimentation Ethics (Standard Practices and Guidelines)* (2001), and the *James Cook University Statement and Guidelines on Research Practice* (2001). The proposed research methodology received clearance from the James Cook University Experimentation Ethics Review Committee (approval number A827).

October, 2007

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Belinda G. Curley

Acknowledgements

I would like to thank my supervisors Prof. Mike Kingsford (JCU) and Dr. Bob Creese (NSW, DPI) for guidance and intellectual input throughout my PhD. Special thanks to Mike for supporting my unorthodox approach to completing a temperate PhD in a tropical climate, and for his passion for 'panmictic' populations. A huge thank you to my undercover supervisor Dr. Tim Glasby, for lending his expertise on asymmetrical ANOVAs, experimental design, assistance in the field, and reviewing the MPA Chapter (I owe you a few hundred donuts). Thanks to Prof. Michael Gillings for his friendship, support, enthusiasm, assistance with field work, editing of multiple chapters, and patience in teaching an ecologist the dark magic of molecular biology (eggplants).

To my father, Alan Curley, who assisted in all aspects of field work, undertaking many 'pleasure dives' in the cold, dirty, raging southern seas in the name of science. For your dedication, encouragement, skill with the hack saw, intellectual input, and watching my back particularly on those bad days - thank you - there would be no data without you. Collection of Luderick for genetic analyses and tagging (which unfortunately didn't make it into this thesis) would not have been possible without the assistance of members of NSW recreational fishing clubs and staff at NSW fisheries. Special thanks to: Glen Onysko ('Esky'), Garry Bonnington ('Bonno'), Paul Cooper, Malcolm Poole, Jim from Currarong, Tony from Bass Point, Bob Thompson, Barry Wilson, Simon and co. from the Newcastle Neptunes, Graham Housefield, Simon Hartley, and James Haddy. Thank you to Marjorie Hemmings for collecting data on fishing effort for Toowoon Bay.

Discussions with Mike Kingsford, Tim Glasby, Michael Gillings, Heather Patterson, Vanessa Miller-Sims, Yi Hu, Lyn Van Herwerden, Dean Jerry, Line Bay and Adam Stowe were valuable in establishing appropriate laboratory and statistical techniques, and/or significantly improving drafts of the thesis. Special thanks to Michael Britt for proof-reading the final product.

Thanks to Vanessa Miller-Sims for reviewing the genetics components, her beautiful singing voice, being my swimming buddy, and her continuing friendship from the northern hemisphere (Hawaii here we come!). I thank Heather Patterson (M.B.) for invaluable comments on multiple drafts of the otolith chemistry chapter and for being my 'disabled' Castle Hill walking partner (BAK, J.B.). To Karin Ulstrup for her general enthusiasm, particularly on those de-stressing walks up the goat track! To Janelle Eagle for understanding every frustration of the PhD process. Thanks to (Dr) Jillian Keating for continuous support and listening to my many 'raves' (no textas required). To Felicity Smith (Grace, 99, Foxtrot Sierra) for her persistent encouragement and excellent company at Cheyne St and at Uni. This is Bravo Charlie signing out - FINALLY!! Thanks to Kathy Danaher, Peter Said, and Michele Dunscombe for their friendship and support during my time in Townsville.

I would like to thank members of the Kingsford lab for their unique contributions to PhD life: Mark O'Callaghan, Kathy Danaher, Mike Cappo, Felicity Smith, Lisa Gershwin. Thanks to Katie Munkres and Selma Klanten (for housing the homeless). Thanks to all the staff at JCU who provided technical support and encouragement. Special mention must go to Vince and Bailey who rescued me from many computer melt-downs, and Ros Burgess who made my external years so much easier. Thank you to Jodie Wilson and the girls in the TRC for their good humour and support. To my flat mates Ann Penny, Alex Carter, Felicity Smith and the Eyre St gang for their wonderful company and encouragement. Thanks to the 'Emma lab' (Mike, Marita, Paul, Sammy and Joss) at Macquarie University for their friendship, technical assistance with genetics work, and tolerating an ecologist in the lab.

Finally I would like to thank my family. To my father who installed in me a great respect and love for the southern seas and my mother for the strength and determination to follow my heart. To my beautiful sister, Tania, who is always on the end of the line whenever I need her. To my brothers Glen and Darren, and my grandparents (Jim and Dorothy) for their encouragement over this somewhat lengthy process. Finally, to the memory of my pop (Herb), who would have been proud despite the fact that I will be 'just a fish doctor' and we 'are just going to eat them anyway'.

This thesis is dedicated to Michael Britt for his unwavering support, friendship and belief in me over so many years. Thank you Mickey.

'The relentless fury of the Sea
Knows none that it should fear,
A sullen thought is sacrifice
And in its rage will disappear'
MTB

Abstract

Knowledge of scales of dispersal and levels of population connectivity is critical for understanding population dynamics and effective management of reef fishes. These processes are important for effective design of Marine Protected Areas (MPAs) particularly if they are to generate 'spillover' and 'recruitment effects'. Despite this, empirical data across appropriate spatial and temporal scales are limited. This is the first study to focus on dispersal and population connectivity for temperate reef fishes in central NSW, Australia, at scales relevant to the implementation of MPAs (100's m - 100's km). The study provides: (1) empirical data on the localised benefits of small MPAs relative to the mobility of exploited reef fishes; (2) baseline data on the utility of different methods (microsatellite markers and otolith chemistry) for determining levels of population connectivity, and potential scales of benefits of MPAs to unprotected areas. Work on microsatellite markers compared population genetic structure in species which span the post-settlement dispersal potentials of reef fishes in this region, and provides a benchmark for understanding general mechanisms which govern gene flow, and population connectivity, in central NSW.

The response of exploited reef fishes to the establishment of small MPAs (≤ 0.2 km^2), was investigated relative to knowledge of post-settlement movement. Two established MPAs were surveyed: Cabbage Tree Bay (CTB) a 2.5 year old 'no-take' MPA, and Gordon's Bay (GB) a 12.5 year old MPA closed to spear fishing only. Abundances and sizes of four 'sedentary' and three 'mobile' fishes within each MPA were compared with three control locations at six times over two years. Temporal variation in abundances suggested that MPAs did not encompass the movement of most species, with the exception of two 'sedentary' species (*Cheilodactylus fuscus* and *Achoerodus viridis*). However, generalizations could not be made between estimated mobility, duration of protection and MPA response. Densities of legal-sized *C. fuscus* were 2.8-times higher and fish were larger within GB relative to controls. Legal *C. fuscus* were more abundant in shallow areas of GB indicating that spear fishing influences local depth distributions. Surprisingly, mean densities of legal-sized 'mobile' *Acanthopagrus australis* were 2.6-times higher in CTB relative to controls, with a similar trend for GB, and for *Girella tricuspidata* in CTB. Response of 'mobile' species to protection was indicative of pre-existing differences between MPAs and controls, immigration rather than recruitment of fish, and/or intraspecific variation in movement. The lack of detectable effect for all other species and differential response between MPAs were attributed to mobility relative to the scale of MPAs, inadequate protection of habitats or depths, population recovery time, and partial protection versus 'no-take' status of MPAs. Overall results emphasise that small MPAs can have significant ecological value, even for highly mobile species. Importantly, as MPAs become smaller their location relative to habitat and depth, local aggregations, recruitment 'hotspots', adjacent habitats, and existing fishing pressure is critical in determining responses and rates of recovery.

Microsatellite markers were developed to provide information on population connectivity at scales ≤ 400 km for reef fishes with low (*Parma microlepis*) and high post-settlement dispersal capabilities (*G. tricuspidata*). It was hypothesized that *P. microlepis* would exhibit spatial genetic structure and a significant pattern of isolation-by-distance (IBD) at these scales, whereas *G. tricuspidata* would not. Genetic differentiation at seven microsatellite loci in *P. microlepis*, and six loci in *G. tricuspidata* were examined across multiple spatial scales. *P. microlepis* was collected from; sites (separated by 1-2 km), nested within locations (separated by 10-50 km), nested within three regions (separated by 70-80 km). *G. tricuspidata* were collected from a subset of the locations sampled for *P. microlepis.* This included five locations (separated by 50-60 km) spanning three sampling regions (separated by 70-100 km). There was no evidence that post-settlement dispersal capabilities influenced genetic structure. Broad-scale genetic homogeneity and lack of IBD was well supported for both species. The proportion of the total genetic variation attributable to differences among sampling regions, locations or sites was effectively zero (e.g. $\Phi_{PT} \leq 0.003$ and $R_{ST} \leq 0.004$). The geographic distribution of genetic diversity and the high polymorphism (*P. microlepis*, H_E 0.21-0.95; *G. tricuspidata*, H_E 0.65-0.97) was indicative of high mutation rates, large effective population sizes, and high rates of gene flow. Genetic homogeneity for fishes and invertebrates in central NSW suggests that gene flow important to genetic structure is driven by factors influencing pre-settlement dispersal such as the East Australian Current (EAC) and habitat continuity. Thus, genetic homogeneity is likely in other exploited reef fishes in this region which have similar pre-settlement durations (≥ 2 weeks). Scales of genetic homogeneity may not reflect demographically relevant dispersal distances. However, it does imply that populations of *P. microlepis* and *G. tricuspidata* are well connected from an evolutionary perspective and have large effective population sizes. This reduces the genetic risks associated with natural or anthropogenic declines in local populations. Furthermore, genetic diversity across spatial scales ≤ 400 km could be conserved within small MPAs as 99-100% of the total genetic variation for both species was represented within 1-2 km of reef. Future studies using genetics to determine population connectivity of reef fishes in central NSW should focus on species with very low dispersal capabilities, small population sizes, short life spans, and whose habitats are rare or patchily distributed along-shore.

The use of otolith chemistry as a natural tag requires the presence of differences in the aquatic environment that translate into differences in otolith chemistry. Consequently, most studies focus on populations distributed across large environmental gradients and spatial scales. This study examined spatial variation in otolith chemistry of the territorial damselfish *P. microlepis* at fine spatial scales in an exclusively marine environment. Solution-based inductively coupled plasma-mass spectrometry was used to measure the integrated otolith chemistry of individual fish, reflective of average environmental differences among regions (separated by 70-80 km), locations within regions (separated by 10-50 km), and between sites within locations (separated by 1-2 km). Mean concentrations of Sr/Ca, Ba/Ca, Mg/Ca, Mn/Ca, Cu/Ca, and Zn/Ca and multi-element signatures varied among regions, locations and sites. Fine scale differences accounted for the majority of the variability in the data and there was a trend for unique chemistries at some sites and locations. Multi-element signatures were good spatial discriminators, with 75-80% of fish correctly classified to the regions in which they were collected. It was difficult to establish simple causal relationships for variation in individual elements. However, regional multi-element signatures were highly correlated with the behaviour of the EAC which delivers water masses varying in chemistry, temperature and salinity to the different regions. Results demonstrate that the magnitude of environmental variability within open coastal regions such as central NSW facilitates the use of otolith chemistry for determining population connectivity of reef fishes at scales < 100's km.

The thesis provides clear implications for management of reef fishes in central NSW, testable hypotheses, and priorities for future research. Overall results demonstrate the ecological value of small MPAs for protecting reef fishes of varying mobility, as well as population genetic diversity representative of broader-spatial scales. The determination of scales of 'spillover' of eggs, larvae and adults remains the greatest challenge. This study suggests that levels of gene flow will limit the utility of microsatellite markers for providing information on population connectivity for most reef fishes in central NSW. Given this, a combination of otolith chemistry, artificial tags, and modelling are the most promising techniques for future studies. Such studies should focus on species which demonstrated localised responses to MPA (e.g. *C. fuscus*, *G. tricuspidata*, and *A. australis*).

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