The effects of ocean acidification and warming on the early life history stages of corals

Thesis submitted by

Chia-Miin **CHUA** BSc (Hons)

In January 2012

For the degree of Doctor of Philosophy in Marine Biology

within the ARC Centre of Excellence for Coral Reef Studies and the School of Marine and Tropical Biology

James Cook University

Townsville Queensland Australia

Statement of Access

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

I understand that as an unpublished work this thesis has significant protection under the Copyright Act and I do not wish to put any further restrictions upon access to this thesis.

	23/01/2012
(Signature)	(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 my 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 Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

	23/01/2012
(Signature)	(Date)

Electronic copy declaration

I, the undersigned, the author of this work, declare that the electronic copy of this thesis provided to the James Cook University library, is an accurate copy of the print thesis submitted, within the limits of the technology available.

	23/01/2012
(Signature)	(Date)

Statement on the contribution of others

Some of the chapters of this thesis are also manuscripts that have been submitted for publication in peer-reviewed journals or are in preparation for submission. Several researchers have made contributions to these manuscripts and it is necessary to recognise their contribution.

Chapter 2 is a manuscript currently in review at 'Coral Reefs' and is co-authored by W. Leggat, A. Moya and A. H. Baird. Experiments for this manuscript were performed by CMC and AM. The statistical analyses were performed by CMC and AHB. AHB, AM and WL provided constructive comments in shaping the manuscript. All authors provided intellectual input into this manuscript.

Chapter 3 is a manuscript currently in review at PLOS one and is co-authored by W. Leggat, A. Moya and A. H. Baird. AHB and WL provided ideas and helped to design the study. Experiments for this manuscript were performed by CMC and AM. The statistical analyses were performed by CMC and AHB. AHB, AM and WL provided constructive comments in shaping the manuscript. All authors provided intellectual input into this manuscript.

Chapter 4 is a manuscript nearing submission and is co-authored by W. Leggat, A. Moya and A. H. Baird. Experiments for this manuscript were performed by CMC and AM. The statistical analyses were performed by CMC and AHB. AHB, AM and WL provided constructive comments in shaping the manuscript. All authors provided intellectual input into this manuscript.

I was supported by a postgraduate scholarship from the Ministry of Higher Education of Malaysia. Funding from this study came from ARC grant to WL, ARC future fellow grant to AHB and GRS research scheme to CMC. Fieldwork assistance was provided by E. Woolsey, L. Huisman, G. Torda, P. Cross, S. Sprungla, D. Miller's lab crew and Willis's lab crew. Technical support for culture system was provided by JCU Marine Aquarium Research Facility Unit (MARFU). L. Harrington provided crustose coralline algae (CCA) identification and constructive comments to the experiment set up and CCA culture.

Acknowledgements

I thank everyone who has assisted me over the years with this PhD and I am particularly grateful to the people mentioned below. Apologies to anyone that I have forgotten to mention, and I hope I have thanked you along the way.

First, I would like to thank my supervisors and JCU staff members who have spent time providing valuable guidance and feedback. I thank my primary supervisors Andrew Baird and Bill Leggat who were instrumental in my development as an independent researcher. I also thank Aurelie Moya for her continuous support and countless late night's sessions in the lab working on this study. I am very grateful for the valuable insights gained through discussion and advice from Maria Byrne and I thank Lindsay Harrington for her knowledge, advice and information on the settlement substrate component in this study.

I would like to thank Philip Munday for letting us replicate and modify his ocean acidification manipulation system. For technical assistance, I would like to thank Geoff Endo, Rob Gegg, Ross Barrett and the MARFU team. And to Peter Schupp and Alex Kerr from University of Guam, thank you for your generosity and collaboration in this study.

For financial assistance, I acknowledge the support of James Cook University and the Australian Research Council. I was supported by the Ministry of Higher Education Malaysia. And I thank Great Barrier Reef Marine Park Authority for allowing us to conduct this research on Australian reefs. Thank you CSIRO, ACRS and ANNIMS for travel subsidies to conferences.

I would like to give a special mention to everyone that has helped me with my field and laboratory work, especially Erika Woolsey, Greg Torda, Lotte Huisman, Erin Graham and Peter Cross. Thank you for making the strenuous coral collection, groundhog days and the late nights awesome and fun. And thanks to everyone who has been involved in the various adventure trips and 'coral sex-trade'. It is through those experiences that I have discovered the beauty of science and new discoveries. Very special thanks to Kellie Johns who has continuously providing useful comments to my manuscripts and significantly improved my writing skills in a second language. Thank you to Duan Biggs for inspiring numerous creative artworks, and for bringing humour to Room 105 and the Centre of Excellence for Coral Reef Studies.

Finally I would like to thank my family: Ju, Heng, Hui, Ma and Pa; and friends: Sally, Daisie, JK, Becs, Dom, Andy, Darren, Mi, Steph, Susie and lots more, for their support and encouragement through tough times. Thank you for always being there for me. I dedicate this thesis to my partner Ryan Anderson, for being the inspiration of my life, and for the patience and TLC in our relationship.

Contents

List of Tables

List of Figures

Abstract

The rapid increase in carbon dioxide (CO_2) in the atmosphere since the industrial revolution is heating the earth and decreased the ocean's pH level. Sea temperature is predicted to rise by between 2 to 4 °C and ocean pH is predicted to decrease 0.2-0.4 units by the end of this century. These changes, along with associated changes in the carbonate chemistry of seawater, are predicted to disrupt calcification and affect the physiology of many marine organisms. While the effects of ocean acidification (OA) on adult scleractinian corals have been extensively studied, until very recently, the effects of OA on the ecology of the early life history stages of corals remained largely unexplored. Similarly, while the effects of temperature on adults and early life history stages of corals are well known, the possible synergistic effects of temperature and OA have not been examined. It is important to assess the effect of OA on the early life stages of corals in order to predict the likely effects on population dynamics. In addition, such research will provide useful guidance for managing coral reefs. To address these critical knowledge gaps, I explored the effect of OA and temperature on fertilization, development, survivorship and metamorphosis using gametes and larvae of a number of abundant scleractinian corals from the Great Barrier Reef. In the first series of experiments, I used four treatment levels of pCO_2 corresponding to current levels of atmospheric CO_2 (approximately 380 ppm), and three projected values within this century (550, 750 and 1000 ppm), to test whether fertilization, embryonic development, larval survivorship or metamorphosis was affected by OA. None of these variables were consistently affected by pCO_2 suggesting that there will be no direct ecological effects of OA on the pre-settlement stages of reef corals, at least in the near future. In a second series of experiments, I tested the effect of OA in combination with elevated temperature on the

response variables mentioned above. We used four treatments: control, elevated temperature (+2°C), decreased pH (600-700 ppm) and a combination of elevated temperature and acidity. There were no consistent effects of OA on fertilization, development, survivorship or metamorphosis either alone, or acting synergistically with temperature. In contrast, temperature consistently increased rates of development, but otherwise had little effect. I conclude that temperature is more likely to affect the ecology of the early life history stages of corals in the near future, mostly by speeding up rates of development and therefore altering patterns of connectivity among reefs. In the third set of experiments, I compared the effects of ocean acidification on the larval metamorphosis of a spawning coral *Goniastrea retiformis* and a brooding coral *Leptastrea cf transversa* in Guam. Again, metamorphosis was not consistently affected by pCO_2 in either species. These results suggest that the mode of reproduction does not affect the larval response to pCO_2 and furthermore, there will be no direct effects of ocean acidification on settlement rates of reef corals, at least in the near future. In the final set of experiments, I tested the effect of ocean acidification on its own and in combination with elevated temperature on the growth of juveniles of *Acropora millepora* and *Acropora tenuis* using the treatment levels described above. Neither OA nor temperature had any significant effect on growth or the pattern of skeleton formation in these species. I concluded ocean acidification is not a threat to the early life history stages of corals in the foreseeable future.