Fuentes, Mariana Menezes Prata Bezerra (2010) ***Vulnerability of sea turtles to climate change: a case study within the northern Great Barrier Reef green turtle population.*** **PhD thesis, James Cook University.**

Vulnerability of sea turtles to climate change: A case study with the northern Great Barrier Reef green turtle population

PhD thesis submitted by
Mariana Menezes Prata Bezerra **FUENTES**
(BSc Hons)
February 2010

For the degree of Doctor of Philosophy
School of Earth and Environmental Sciences
James Cook University
Townsville, Queensland 4811
Australia

"The process of learning is often more important than what is being learned"

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Statement of contribution of others

Research funding:

- Australian Government's Marine and Tropical Scientific Research Facility,
- Great Barrier Reef Marine Park Authority,
- National Geographic,
- Professional Association of Diving Instructors (PADI) Foundation,
- Torres Strait Regional Authority,
- Wentworth Group of Concerned Scientists,
- Norman Wettenhall Foundation,
- James Cook University, Australia.

Research in-kind support:

- Department of Environment and Resource Management (DERM),
- Marine Parks,
- Undersea Explorer,
- Earthwatch Institute,
- Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO),
- Queensland Parks and Wildlife Service.

Stipend:

- Australian Postgraduate Award.

Supervision:

- Dr Mark Hamann, School of Earth & Environmental Sciences, James Cook University,
- Dr James Moloney, School of Earth & Environmental Sciences, James Cook University,
- Dr Col Limpus, Department of Environment and Resource Management.

Statistical, analytical, and modelling support:

- Jeffrey Maynard, University of Melbourne and the Great Barrier Reef Marine Park Authority (Chapter 3),
- Jeremy Werdell, Science Systems and Application Inc. (Chapter 3),
- Dr Deborah Abbs, CSIRO (Chapter 5),
- Dr Joshua Cinner, ARC Centre of Excellence for Coral Reef Studies (Chapter 6).

Editorial assistance:

- Dr Mark Hamann (whole thesis),
- Dr James Moloney (Chapters 1-5),
- Dr Col Limpus (Chapters 2-7)
- Sharon Read (Chapters 1 and 8),
- Professional editor, Online English editing services (Chapters 2 and 7),
- Dr Scott Smithers, James Cook University (Chapter 2),
- John Dawson (Chapters 2 and 4),
- Ian Bell, Department of Environment and Resource Management (Chapter 3),
- Rosemary Dunn, James Cook University (Chapter 4),
- Dr Joshua Cinner, ARC Centre of Excellence for Coral Reef Studies (Chapters 5 and 6),
- Biotext professional editors (Chapter 5).

Permits

Field work for this thesis complies with the current laws of Australia, and all permits necessary for the project were obtained (QPW permit no. WISPO4316207 and JCU Human Ethics H3377).

Acknowledgements

I feel extremely privileged to have undertaken such an exciting and challenging project.

However, having pursued a multi-disciplinary project at remote islands on a rather "uncertain and contradictory" topic the road has not always been smooth. During the last three and a half years I have dealt with steep learning curves and with innumerous analytical, logistical and personal challenges. Nevertheless, I was very fortunate to have a variety of people and funding agencies supporting this project and helping along the way.

I am very grateful for the support and guidance provided by my supervisory committee: Mark Hamann, Col Limpus and James Moloney.

I thank **Mark** for believing in me and "picking me" to work on such a stimulating project. Mark's help extends beyond the academic arena and I will always be thankful for all the support during the not so glamorous aspects of my field work. I will always have "fond" memories of digging massive sand pits to look for tiny data loggers, conducting beach profiles on exceedingly hot days, hiding from scary tropical storms and impatiently waiting long hours for a dinghy to pick us up. Mark's presence and humour certainly made these "occurrences" more "enjoyable".

I am also extremely thankful to **James** for being my GIS whiz and for always being keen to help no matter how "stupid" or complex my questions were.

I am grateful to my external supervisor, **Col,** whose guidance and depth of knowledge of sea turtles was indispensable. But most importantly, for challenging me to think outside the box; my work has certainly benefited immensely from his comments and suggestions.

My appreciation is extended to many colleagues that gave their time to brainstorm, discuss and provide important comments and suggestions during my PhD, special thanks to **Scott Smithers, Kevin Parnell, Emma Gyuris, Roger Beeden, Paul Groves, Mark Read, Frank Loban, Deborah Abbs, Joshua Cinner, Alana Grech,** and **Vanessa Valdez**.

I am also indebted to many of the **SEES's staff** for being so helpful and for providing the guidance and the answers to the little things from completing the necessary paperwork to understanding the bureaucracy necessary for a smooth ride at University. Special thanks to **Beth, Penny, Glen, Melissa** and **all the other girls** at reception who helped me fill a gazillion travel requests, purchase orders and petty cash forms. I am also indebted to **Rob Scott** and **Clive Grant** for all their help with absolutely anything from organizing field gear to fixing my computer.

Data were kindly provided to me by: the Australian Bureau of Meteorology; Australian Commonwealth Scientific and Research Organisation; and Queensland Parks and Wildlife Service.

While conducting my field work on remote islands in Torres Strait and the northern Great Barrier Reef I had the privilege to meet and work with some exceptional people, whose assistance was indispensable for this project. I want to especially thank **Moses Wailu, Ian Bell, Kenny Bedford, Frank Loban, Eddie Sailor, Ronald Fuji, Damian Miley, and Qamar Schuyler**. I am also thankful to the Traditional Owners of Bramble Cay, Dowar Island and Raine Island for allowing access and granting permission to work on their land and to have the opportunity to work in such magical places.

I am also extremely grateful to the Australian Marine Parks personnel, especially **Tenielle Brown, Dan Schaper, Ian Osborn, John Hicks, Richard Lindeman, Pat Kirby, Dave Fuller, Chris Billett, Sebastian Selwood, Andrew Simmonds, Simeon Miglioranza, Joel Hitchcock, Andrew Bates, Aaron Ledgard, Brenton Haigh** and **Leroy Brown** for helping deploy and retrieve data loggers at the remote study sites, without their help this aspect of my work would not have been possible. My appreciation is extended to all the colleagues, friends and volunteers that have collaborated and helped during my field work. I thank you all for your dedication, patience and hard work under physically and mentally demanding times.

I am also extremely thankful to the following funding agencies that provided generous support for this project: the Australian Government's Marine and Tropical Scientific Research Facility, Great Barrier Reef Marine Park Authority, National Geographic, the PADI Foundation, Department of Environment and Resource Management (DERM), including Queensland Parks and Wildlife Service, Torres Strait Regional Authority, Norman Wettenhall Foundation, Wentworth Group of Concerned Scientists, and the School of Earth and Environmental Sciences, James Cook University.

But most importantly I want to thank my friends and family who kept me sane and were always present to provide moral support and encouragement. Special thanks to my Australian sisters: **Di, Broka, Vanessita, Jambo, Mile, April,** and **Nanou,** your love and friendship was essential to keep me going… Knowing you ladies has inspired me immensely to always strive to be a better woman and achieve my goals. I was fortunate to share an office, which became a home, with **Vanessita**. Sweetie your presence was more important than you can imagine, thanks for being there to share the joys of good days and supporting me through the tough ones, for always listening, for all the cups of needed coffee, for calming me down when I got frustrated, for teaching me how to be more Zen about life and others, for answering my dumb questions when my brain no longer worked, for being a nerd with me and getting excited about nerdy things, for the company during the long hours, and for the innumerous adventures… I couldn't have asked more from an office mate, friend and sister…

I am also extremely thankful to all my Capoeira friends (**Complicado, Uakari, Rosinha, Amanha, Jambo, Papagaio, Soldado,** and **Lagosta**) who were used as "punching bags" in moments of stress and always provided the Axe necessary for me to forget about my PhD when necessary. Similarly, my **Dharma friends** also deserve some mention as their presence and guidance illuminated my way with important teachings and meditation techniques.

Special thanks to **Joshua Cinner**, for all the love, support, companionship and encouragement; you have inspired me immensely through the last years and without a doubt helped shape the person and academic I am today…. Words can't describe all I learned from you and how thankful I am for everything… It is my hope that we continue to inspire each other and contribute in the future.

I am also extremely thankful and glad that my body, mind and spirit endured the long stressful hours, extraneous field work and anxious thoughts and that I was able to give my best to this project. It is my sincere hope that this work offers constructive management tools to assist managers to detect and mitigate the impacts of climate change on sea turtles in the future.

"The smallest act of kindness is worth more than the grandest intention"

Publications associated with this thesis

Peer-Reviewed Publications

Fuentes MMPB, Dawson J, Smithers S, Limpus CJ, and Hamann M (in press) Sedimentological characteristics of key sea turtle rookeries: potential implications under projected climate change. Journal of Marine and Freshwater Research. (Chapter 2)

Fuentes MMPB, Hamann M, and Limpus CJ (2010) Past, current and future thermal profiles for green turtle nesting grounds: implications from climate change. Journal of Experimental Marine Biology and Ecology, 383, 56-64 (Chapter 3)

Fuentes MMPB, Maynard JA, Guinea M, Bell IP, Werdell PJ, and Hamann M (2009) Proxy indicators of sand temperature help project impacts of global warming on sea turtles. Endangered Species Research Journal 9, 33-40 (Chapter 3)

Fuentes MMPB, Limpus CJ, Hamann M, and Dawson J (in press) Potential impacts of projected sea level rise to sea turtle rookeries. Aquatic Conservation: Marine and Freshwater Ecosystems. DOI:10.1002/aqc.1088 (Chapter 4)

Fuentes MMPB, Limpus CJ, and Hamann M (in review) Vulnerability of sea turtle nesting grounds to climate change. Global Change Biology. DOI: 10.1111/j.1365-2486.2010.02192.x (Chapter 7)

Fuentes MMPB and Hamann M (2009) A rebuttal to the claim natural beaches confer fitness benefits to nesting marine turtles. Biology letters, 5, 266-267 (not contained in the thesis)

Manuscripts in review

Fuentes MMPB, and Abbs D (in review) Sea turtles, cyclones and climate change: assessing the affects of projected changes in cyclonic frequency on sea turtles. Journal of Marine Ecology Progress Series (Chapter 5)

Fuentes MMPB, and Cinner JE (in review) Impact of climate change to sea turtle nesting grounds: using experts' opinions to inform management. Journal of Environmental Management (Chapter 6).

Manuscripts in preparation

Fuentes MMPB, Moloney J, Limpus CJ, and Hamann M (in prep.) Historical disturbance of cyclones to sea turtles in eastern Australia. To be submitted to Marine Biology (Chapter 5)

Fuentes MMPB, and Hamann M (in prep.) Influence of nest site selection on the susceptibility of climatic events to turtle nests. To be submitted to Animal behaviour (Chapters 2-5)

Fuentes MMPB, Grech A, Fish M, and Hamann M (in prep.) Feasibility, risks, and constraints of management options to mitigate the impacts of climate change on sea turtles. To be submitted to Biological Conservation (Chapter 8)

Books and book chapters

Fuentes MMPB (2010) Myrtle's battle against global warming. Published by the Reef & Rainforest Research Centre Limited.

Fuentes MMPB, Hamann M, and Lukoschek V (2009) Marine reptiles and climate change. In: A marine climate change impacts and adaptation report card for Australia 2009 (Eds. Poloczanska ES, Hobday AJ, and Richardson AJ) NCCARF Publication 05/09, ISBN 978-192160903-9.

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Hamann M, Sutherland L, Loban F, Kennett R, **Fuentes MMPB** and Limpus CJ (2008) Hot water for marine reptiles: research into sea turtles and climate change. Wildlife Australia 45(4) p12-19.

Fuentes MMPB (2007) Some like it hot. Australasian Science. Nov-Dec. p 34-36.

Fuentes MMPB, Dawson J, Smithers S, and Hamann M (2007) Surficial carbonate facies across key rookeries for the northern Great Barrier Reef green turtle population stock. Technical report for the Environment Protection Agency.

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Fuentes MMPB, Limpus CJ, Hamann M, and Dawson J (2009) Community assistance in determining the potential effects of projected sea level rise on marine turtles. Australian National Network in Marine Science Inaugural Conference: Marine Science in Tropical, Temperate and Southern Oceans (2009) Hobart, Australia

Fuentes MMPB (2009) Sea turtles, climate change and future challenges for management. The 10th International Congress of Ecology: Ecology in a Changing Climate (2009) Brisbane, Australia

Fuentes MMPB, Limpus CJ, and Hamann H (2009) How will the largest green turtle population in the world be affected by climate change? Marine and Tropical Sciences Research facility Annual Conference (2009) Townsville, Australia

Fuentes MMPB, Limpus CJ, Hamann H, and Moloney JM (2009) Assessing the vulnerability of sea turtle populations to predicted geographic shifts in cyclone patterns. 29th Symposium on Sea Turtle Biology and Conservation (2009) Brisbane, Australia

Hamann M, and **Fuentes MMPB** (2009) Raine Island: Issues and implications. 29th Symposium on Sea Turtle Biology and Conservation (2009) Brisbane, Australia

Fuentes MMPB, Limpus CJ, Hamann M, and Dawson J (2009) Community assistance in determining the potential effects of projected sea level rise on marine turtles. 29th Symposium on Sea Turtle Biology and Conservation (2009) Brisbane, Australia

Fuentes MMPB, Dawson J, Smithers S, and Hamann M (2008) Traits of surficial carbonate sediments at reef Islands: implications of climate change to island fauna. 11th International Coral Reef Symposium (2008) Florida, USA

Fuentes MMPB, and Dawson J (2007) Identifying superficial carbonate facies at key sea turtle rookeries to investigate the potential effects of climate change on turtle populations of the northern Great Barrier Reef. Greenhouse 2007: the latest science & technology (2007), Sydney, Australia

Other publications generated during my candidature

The following publications were also published during my candidature:

Peer-Reviewed Publications

Cinner JE, **Fuentes MMPB**, and Randriamahazo H (2009) Exploring social resilience in Madagascar's marine protected areas. Ecology and Society 14(1): 41 URL: http://www.ecologyandsociety.org/vol14/iss1/art41/

Fuentes MMPB, Lawler IR, and Gyuris E (2006) Dietary preferences of juvenile green turtles (*Chelonia mydas*) on a tropical reef flat at Green Island, Queensland, Australia. Wildlife Research 32, 671-678

Book Chapter

Cinner JE, and **Fuentes MMPB** (2008) Human Dimensions of Madagascar's Marine Protected Areas. In: Ten years after bleaching consequences and issues facing countries in the Indian Ocean (Eds. Obura D, Tamelander J, and Linden O) pp. 397-404. CORDIO/Sida-SAREC, Mombasa.

Reports and popular literature

Fuentes MMPB (2009) Hawksbill turtles at Masig Island II. Technical report for the Torres Strait Regional Authority and Kailag Enterprises.

Fuentes MMPB (2009) Hawksbill turtles at Masig Island. Technical report for Torres Strait Regional Authority and Kailag Enterprises.

Cinner JE, and **Fuentes MMPB** (2006) A Baseline Socioeconomic Assessment of Fishing Communities in Northern Madagascar. Report to the Wildlife Conservation Society Madagascar Marine Program.

Abstract

Sea turtles are vulnerable to aspects of climate change because they have life history, physiological attributes and behaviour that make them extremely sensitive to environmental changes. Arguably, the more detectable impacts of climate change to sea turtles will occur during their terrestrial reproductive phase (egg laying, egg incubation and hatchling success phase) since there are clear, and relatively straightforward, effects of increased temperature, sea level rise and cyclonic activity on sea turtle nesting sites and reproductive output.

Indeed, there has been a recent increase in research activity focusing on the potential impacts and implications of climate change to sea turtles' terrestrial reproductive phase. While first identified as an issue in the mid 1980s recent studies have begun to investigate and predict how specific climatic processes will affect sea turtle's nesting habitats and reproductive output. However, the studies conducted to date are limited temporally, because (1) they predict how a single climatic process will affect sea turtles, yet processes are likely to occur simultaneously and cause cumulative effects, and (2) they typically focus only on one nesting ground used by a particular turtle population and this approach does not provide a full understanding of how a population (management unit) will be affected. Consequently, there is a need for a structured approach to investigate how multiple climatic processes may affect the full range of nesting grounds used by a turtle population.

In my thesis I address the issue of cumulative impact by using a systematic and comprehensive methodology to assess how multiple climatic processes will affect the northern Great Barrier Reef (nGBR) green turtle population under a conservative and an extreme scenario of climate change for both 2030 and 2070. First, I identified how key processes: (1) change in sediment traits, (2) increased temperature, (3) sea level rise, and (4) cyclonic activity will affect the nesting grounds (n= 7) that represent the nesting habitat for 99% of the nGBR green turtle population. After I determined how each process will potentially affect the selected nesting grounds, I used expert opinion to gather information on the relative impact of each process on sea turtle nesting grounds. This information was then incorporated into a climate change vulnerability assessment framework.

To explore how changes in sediment will impact the nGBR green turtle population I conducted two steps. First, I described the sediment types and identified the reef-building organisms of each nesting ground. I then reviewed the literature on the vulnerability of each identified reef-building organism to climate change and how various sediment characteristics ecologically affect sea turtles. I found that the sediment from each of the studied nesting grounds is predominantly composed of well sorted, medium-grained to coarse-grained, sands and are dominated by Foraminifera, molluscs

or both. Dissimilarities in the contemporary sedimentology between the nesting grounds suggest that each will respond differently to environmental impacts such as increased temperature, sea level rise and ocean acidification. The implications of changes to island sedimentology on sea turtle ecology include changes in nesting and hatchling emergence success, and reduced optimal nesting habitat. Both of these factors can influence sea turtles' annual reproductive output and thus have significant conservation ramifications.

The second key process I examined was potential changes to incubation temperatures. For this, I first conducted a systematic process to select the best predictive model of sand temperature. Using Akaike Information Criterion I determined that a model incorporating both sea surface and air temperature as proxy indicators of sand temperature is the best model to predict future sand temperature for the study region. I then used sand temperature (at clutch depth), the developed models and air and sea surface temperature projected by the International Panel of Climate Change (IPCC) and the Australian Commonwealth Scientific and Research Organisation (CSIRO) to predict sand temperature for the selected nesting grounds. My models predicted a feminization of annual hatchling output into the nGBR green turtle population by 2030. Predictions are bleaker for 2070, when some of the nesting rounds (Bramble Cay and northern Dowar and Milman Island) used by this population are predicted to experience temperatures near or above the upper thermal incubating threshold (e.g. 33 ˚C) and likely cause a decrease of hatching success. Importantly, I identified that some nesting grounds (e.g. Raine Island, western Milman Island and Sandbank 7) will still produce male hatchlings, even under the most extreme scenario of climate change. This is crucial for future management as managers may choose to protect important male-producing regions to balance future population viability.

Further impacts to the nGBR green turtle population will potentially occur from sea level rise. To investigate how SLR will impact the different nesting grounds I first conducted beach profiles at each of the selected nesting ground and used the profile information to create a digital elevation model for each of them. Second, I used geographic information system (GIS) to map and quantify areas that will be inundated under various SLR scenarios. Using the predicted sea level rise values from the IPCC and CSIRO, my results indicated that up to 34% of available nesting area across all the selected nesting grounds may be inundated as a result of predicted levels of SLR. My data indicated that low sandbanks will be the most vulnerable to SLR and nesting grounds that are morphologically more stable, such as Dowar and Raine Islands, will be less vulnerable.

More positively, my study indicates that as climate change progresses it is likely that impacts from cyclones to the nGBR green turtle population will be very low. I used eleven of the latest regional climate models to investigate how cyclonic frequency will alter in a warming climate. Most models predicted a tendency for a reduction in cyclonic frequency in the future. Thus a reduction in the impacts that the nGBR green turtle population will experience from cyclones is likely.

The second part of my thesis involved incorporating the predicted impacts from the climatic processes to each nesting ground into a vulnerability assessment framework for climate change. The framework used is based on the IPCC framework for climate change and is described as a function of sensitivity, exposure and adaptive capacity. The framework allowed me to: (1) assess how multiple climatic processes will affect the terrestrial reproductive phase of sea turtles; and (2) investigate how mitigating different climatic factors individually or simultaneously can influence the vulnerability of the nesting grounds. Thus I was also able to provide informed suggestions of management options to mitigate the potential impacts of climate change to the nGBR green turtle population.

The vulnerability assessment indicated that in the short term (by 2030), sea level rise will cause the most impact on the nesting grounds used by the nGBR green turtle population. However, in the longer term, by 2070 sand temperatures will reach levels above the upper transient range and the upper thermal threshold and cause relatively more impact on the nGBR green turtle population. Thus, in the long term, a reduction of impacts from sea level rise may not be sufficient, as nesting grounds will start to experience high vulnerability values from increased temperature. Therefore, a stronger focus on mitigating the threats from increased temperature will be necessary for long term management.

Some of the potential options to mitigate the impacts of increased temperature include changing the thermal gradient at beaches, nest relocation, and artificial incubation. The best management options will be site specific and dependent on a series of factors, including feasibility, risk (interaction and impact on other species and ecosystems), cost, constraints to implementation (both cultural and social), and probability of success in relation to selected sites. Thus, a “toolbox” with various strategies will be needed to address the impacts of increased temperature across the nesting sites used by the nGBR green turtle population.

The main strengths of the framework used here is that it can easily be adapted when information is obtained, and it can be transferable to different sea turtle populations and sea turtle life cycle phases provided the necessary data exist. This framework provides key information for managers to direct and focus management and conservation actions to protect turtle populations in the face of climate change. Indeed results from my thesis have been used by the Australian Government in their development of the outlook report for species and ecosystems of the Great Barrier Reef.

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