This file is part of the following reference:


Access to this file is available from:


*The author has certified to JCU that they have made a reasonable effort to gain permission and acknowledge the owner of any third party copyright material included in this document. If you believe that this is not the case, please contact ResearchOnline@jcu.edu.au and quote [http://eprints.jcu.edu.au/8195/](http://eprints.jcu.edu.au/8195/)*
Spatial models and risk assessments to inform marine planning at ecosystem-scales: seagrasses and dugongs as a case study

Thesis submitted by
Alana Grech
B.Env.Sc. (Hons) University of Adelaide

in November 2009

for the degree of Doctor of Philosophy
in the School of Earth and Environmental Sciences
James Cook University
Statement on the Contribution of Others

Research funding:
Anonymous donor $20,000
Australian Postgraduate Award (stipend for 3.5 years) $63,000
Ethel Mary Read Research Grant, Royal Zoological Society New South Wales $750
Graduate Research School, James Cook University $350
Marine and Tropical Sciences Research Facility $60,000
Postgraduate Travel Award, CRC Reef $900
Queensland Government Growing the Smart State PhD Funding Programme $5,400
School of Earth and Environmental Sciences, James Cook University $2,200

Thesis committee:
Professor Helene Marsh, School of Earth and Environmental Sciences, James Cook University
Dr. Rob Coles, Northern Fisheries Centre, Fisheries Queensland
Dr. James Moloney, School of Earth and Environmental Sciences, James Cook University

Statistical and analytical support:
Professor Helene Marsh
Dr. Rob Coles

Editorial support:
Professor Helene Marsh
Dr. Rob Coles
Dr. Carol Grech
Dr. Mark Hamann
Ms. Jillian Grayson
Acknowledgements

During the time of my candidature I received assistance from many people and organisations. In particular, I am indebted to my supervisors Helene Marsh and Rob Coles. Thank you to Helene for initiating the project and for providing me with the opportunity to conduct interesting and rewarding research in northern Australia. In addition, thank you for your guidance and support over the course of my candidature. Thank you to Rob for your great advice and encouragement and for providing me with the unique opportunity to learn about natural resource management from the perspective of a management agency. Most of all, I thank Helene and Rob for always being accessible and willing to help throughout my candidature.

I am very appreciative of the academic and administrative assistance provided to me by the staff of the School of Earth and Environmental Sciences of James Cook University, especially: James Moloney, Peter Valentine, Bernd Lottermoser, Scott Smithers, Clive Grant, Kevin Parnell, Steve Sutton, Mark Hamann, Ivan Lawler, Alison Cottrell, Adella Edwards, Beth Moore, Glen Connolly, Melissa Crawford, Lesley McCann and David King. Special thanks to Rob Scott for his excellent technical support.

I am also grateful to the support provided to me during my candidature by the staff of James Cook University: Michelle Waycott and Catherine Collier (School of Marine and Tropical Biology); Sue Bird and Barbara Pannach (Graduate Research School); Annette Ryan (Research Office); and Stephen Lewis, Mirjam Maughan, and Michelle Devlin (Australian Centre for Tropical Freshwater Research). Thank you to the staff and students of the labs of Helene Marsh and Bob Pressey, who were excellent sounding boards for my research.

I would like to express my gratitude to the following people and organisations who assisted me during my candidature: Len McKenzie, Mike Rasheed, Jane Mellors, Helen Taylor, Phil Hales, Bev Gibbs, Mai Tanimoto, and Nadia Zeller (Fisheries Queensland); Kirstin Dobbs, Chicka Turner, Darren Cameron, Tony Stokes, Laurence McCook, Mark Read, James Monkivitch, Tony Stokes, and Stephanie Lemm (Great Barrier Reef Marine Park Authority); Mark Kelton, Niall Connolly and Murray Whitehead
(Queensland Department of Environment and Resource Management); and Katharina Fabricius (Australian Institute of Marine Science).

I am grateful to the organisations that funded this project, including: the Australian Government; Royal Zoological Society of New South Wales; School of Earth and Environmental Sciences and the Graduate Research School, James Cook University; Marine and Tropical Sciences Research Facility; CRC Reef; Queensland Government; and an anonymous donor. Thank you to Sheridan Morris and David Souter (Marine and Tropical Sciences Research Facility) for their generous contribution to my research.

Data was kindly provided to me by: the Australian Bureau of Meteorology; Australian Bureau of Statistics; Australian Commonwealth Scientific and Research Organization; Australian Institute of Marine Science; Australian Maritime College; Geoscience Australia; Great Barrier Reef Marine Park Authority; Fisheries Queensland; Queensland Department of Environment and Resource Management; Queensland Transport; Australian Centre for Tropical Freshwater Research; and the School of Earth and Environmental Sciences.

Thank you to my fellow postgraduate students at James Cook University for their support and friendship: Tom Bridge, Jessica Stella, Dean Miller, Marissa Land, Iain Faichney, Mariana Fuentes, James Sheppard, Guido Parra, Amanda Hodgson, Dipani Sutaria, Vanessa Valdez Ramirez, Adrian McMahon, and Kath Larsen. I am especially thankful to Jillian Grayson for her wisdom and good humour.

And finally, thank you to my family and friends, who have been a vital source of entertainment throughout my candidature. Special thanks to Mum and Cathy for their support (academic, emotional and financial!), encouragement and regular care packages.
Abstract

Informing marine planning and the management of species at ecosystem-scales is difficult because data are generally lacking at that scale. Collecting empirical information on the distribution and/or abundance of species across broad spatial scales is expensive and logistically difficult. Accurate and efficient monitoring programmes that assess the response of species to management actions often cannot be conducted at ecosystem-scales due to time, expertise and cost constraints.

The Great Barrier Reef World Heritage Area (GBRWHA) of Queensland, Australia, is the world’s largest World Heritage Area (approximately 348,000 km²) and second largest marine protected area (MPA). The region supports a variety of habitats and species including coastal seagrasses and globally significant populations of the dugong (*Dugong dugon*), a threatened marine mammal. Seagrasses, dugongs and their habitats are exposed to multiple anthropogenic threats along much of the 2,300 km coastline of the GBRWHA. Assessing the effectiveness of the current management arrangements for seagrasses and dugongs and informing the design of new regimes is challenging due to the difficulties associated with data collection and monitoring at the scale of the coastal GBRWHA.

My thesis goal was to overcome the difficulties associated with informing the management of coastal seagrasses and dugongs in the GBRWHA by using spatial models and risk assessments in geographical information systems (GIS). My objectives were to: (1) develop spatial models of seagrasses and dugongs at the scale of the coastal GBRWHA; and, (2) use these models to estimate the risk to coastal seagrasses and dugongs from their anthropogenic threats. This approach allowed me to compare and rank the threats to identify the most severe risks, and to locate specific sites that require conservation actions.

I used spatial information on the distribution of coastal seagrasses and predictor variables along with ecological theory and expert knowledge to inform the design of a Bayesian belief network, and to develop a predictive seagrass habitat model. The Bayesian belief network quantified the relationship (dependencies) between seagrass habitats and eight environmental drivers: relative wave exposure, bathymetry, spatial
extent of flood plumes, season, substrate, region, tidal range and sea surface temperature. The outputs of the modelling exercise were probabilistic GIS-surfaces of seagrass habitat suitability for the entire GBRWHA coast in both the wet and dry seasons at a planning unit of 2 km * 2 km.

Quantitative information on the relative impact of the anthropogenic threats to coastal seagrasses is incomplete or unavailable, and the cumulative impact of multiple threats is difficult to measure and predict. In the light of this uncertainty, I used expert knowledge to evaluate the relative risk of coastal seagrass habitats to their hazards. Vulnerability scores derived from expert opinion, spatial information on the distribution of threats and the probabilistic GIS-surfaces of seagrass habitat suitability were used to delineate areas of low, medium and high relative risk to coastal seagrass habitats. I found that whilst most planning units in the remote Cape York region of the GBRWHA are classified as low risk, almost two thirds of coastal seagrass habitats along the urban coast are at high or medium risk from multiple anthropogenic activities. Reducing the risk to coastal seagrass habitats in 13 sites identified for conservation action would require: (1) improving the quality of terrestrial water that enters the GBRWHA; (2) mitigating the impacts of urban and port infrastructure development and dredging; and, (3) addressing the hazards of shipping accidents and recreational boat damage.

I derived a spatially explicit dugong population model from spatial information on the abundance and distribution of dugongs collected by a 20 year time-series of aerial surveys. Data from the aerial surveys were corrected for differences in sampling intensity and area sampled between surveys prior to the development of the model. I interpolated the corrected data to the spatial extent of the aerial surveys using the geostatistical estimation method of universal kriging. The model estimated the relative density of dugongs across the GBRWHA at the scale of 2 km * 2 km dugong planning units (the same spatial scale as the seagrass habitat model). I classified each dugong planning unit as of low, medium, or high conservation value on the basis of the relative density of dugongs estimated from the model and a frequency analysis.

I compared the spatially explicit dugong population model with information on the distribution of commercial gill-netting activities to estimate the risk of dugong bycatch in the GBRWHA. I found that new management arrangements introduced in the
GBRWHA in 2004 appreciably reduced the risk of dugong bycatch by reducing the total area where commercial netting is permitted. Restructuring of the industry further reduced the total area where netting is conducted. Netting is currently prohibited in 67% of dugong planning units of high conservation value, a 56% improvement over the former management arrangements. I identified four sites where netting is still conducted in dugong planning units of high and medium conservation value. Conservation actions including area closures or modified fishing practices should be considered for these regions.

In addition to commercial gill-netting, dugongs are threatened by Indigenous hunting, trawling, vessel traffic, and poor quality terrestrial runoff. I developed a rapid approach to assess the risk to dugongs from multiple anthropogenic threats in the GBRWHA, and evaluated options to ameliorate that risk. Expert opinion and a Delphi technique were used to identify and rank anthropogenic threats with the potential to adversely impact dugongs and their habitats. I quantified and compared the distribution of these threats with the spatially explicit model of dugong distribution and found that almost all dugong planning units of high (96%) and medium (93%) conservation value in the GBRWHA are at low risk from human activities. Decreasing the risk to dugongs from anthropogenic threats in four sites that I identified for conservation action would require netting or Indigenous hunting to be banned in the remote Cape York region, and the impacts of vessel traffic, terrestrial runoff and commercial netting to be reduced in urban areas.

The approach I developed in this thesis was able to overcome the difficulties associated with informing marine planning and management at ecosystem-scales by using spatial models and risk assessments in GIS to: (1) quantify the spatial distribution of species; and, (2) assess the risk to species and identify sites for conservation action. I was able to achieve this outcome in a data-inadequate environment by combining qualitative assessments on the relative impact of multiple anthropogenic threats with spatial models of species and threat distributions. Implementing conservation actions at the sites that I identified for management will provide the greatest positive result for coastal seagrasses and dugongs at the scale of the GBRWHA. Future research should be directed at understanding the constraints and opportunities for management in the region to ensure that effective implementation of conservation actions can be achieved.
# Table of Contents

Chapter 1  
General introduction  
1

Chapter 2  
Study area and species  
17

Chapter 3  
A predictive model of coastal seagrass distribution for ecosystem-scale marine planning  
35

Chapter 4  
A spatial assessment of the risk to coastal seagrass habitats from multiple anthropogenic threats in the GBRWHA  
55

Chapter 5  
Prioritising areas for dugong conservation in the GBRWHA using a spatially explicit population model  
85

Chapter 6  
A spatial assessment of the risk to dugongs from bycatch  
101

Chapter 7  
Rapid assessment of risk to dugongs from multiple anthropogenic threats in the GBRWHA  
123

Chapter 8  
General discussion  
143

References  
171

Appendix A  
Chapter 3 supporting figures  
187

Appendix B  
Conditional probability table of Bayesian belief network outlined in Chapter 3  
197

Appendix C  
Chapter 4 supporting figures  
203

Appendix D  
Copy of the online survey used to collect information on rankings for the five vulnerability factors from seagrass experts  
215

Appendix E  
Chapter 7 supporting figures  
227
List of Tables

Table 3.1  Description of the six predictor variables that were nodes in the Bayesian belief network. Figures showing the spatial distribution of predictor variables are provided in Appendix A. 43

Table 3.2  The total number of point locality data (Fisheries Queensland) where seagrass was present and absent within various levels of predicted likelihood of seagrass presence from the model. The predictive rate is the proportion of point locality data where seagrass was present within the various levels of predicted likelihoods. 46

Table 4.1  Ranking system for the five vulnerability factors (Halpern et al. 2007; Selkoe et al. 2008). 65

Table 4.2  Descriptive statistics of the scores across responses for each of the vulnerability factors of individual hazards. 69

Table 4.3  Weighted-average vulnerability and certainty scores derived from expert opinion. 70

Table 4.4  Percentage (%) of seagrass planning units of low (< 0.5), medium (0.5 – 0.75) and high (> 0.75) conservation value in the entire GBRWHA and the urban coast and remote Cape York regions with a low, medium and high risk from anthropogenic activities 74

Table 5.1  Isotropic and directional (0˚, 45˚, 90˚ and 135˚) variogram model parameters for dugongs in the GBRWHA. RMSE: root-mean-square error between observed and predicted semivariance; SE: standard error. 94

Table 5.2  Total area (km$^2$) of dugong planning units with high, medium and low conservation value in the entire GBRWHA, urban coast and remote Cape York region. 98

Table 6.1  The five levels of restrictions on commercial gill-netting relevant to dugongs in the GBRWHA. The risk of bycatch of dugongs is low with Level 1 and 2 restrictions. 108

Table 6.2  Evaluation of the assumptions underpinning the analyses. 111

Table 6.3  Percentage of dugong planning units of high, medium and low conservation value in: (1) the entire GBRWHA; (2) urban coast; and, (3) remote Cape York regions where: (1) the risk of dugong bycatch was assumed to be nil because commercial gill-netting is banned; and, (2) no gill-netting actually occurred during: (a) January-June 2005 (post rezoning and industry restructuring) and (b) January-June 2004 (pre rezoning and industry restructuring). The total area considered here is the known area used by dugongs in the GBRWHA as outlined in Chapter 5. 113

Table 6.4  Results of the paired Mann-Whitney U tests comparing commercial netting effort for each planning unit in the January – June periods of 2004 and 2005 within areas of high, medium and low conservation value in the GBRWHA, urban coast and remote Cape York regions. 112
Table 7.1  Individual and composite ratings of the relative impact of anthropogenic hazards to dugongs and their habitats developed by experts using a Delphi technique.

Table 7.2  Area (km$^2$) and percentage of dugong planning units with high, medium, and low conservation value in the entire GBRWHA and the urban coast and remote Cape York regions where the risk of all anthropogenic hazards is low under the current zoning and management arrangements.

Table 7.3  Percentage of dugong planning units of high, medium, and low conservation value in the entire GBRWHA and the urban coast and remote Cape York regions with a low risk from anthropogenic activities under various hypothetical scenarios.

Table 8.1  Priority sites for coastal seagrass and dugong conservation action identified in Chapters 4, 6 and 7.

Table 8.2  Conditions that generate varying levels of resilience and mobility for users of the GBRWHA and its catchments, categorised by their activity and/or industry.
List of Figures

Figure 1.1  (A) Extent of the Great Barrier Reef World Heritage Area (GBRWHA) off the coast of Queensland, Australia. Major regional cities are shown. The coastal waters of the GBRWHA are approximately -15 m below mean sea level as illustrated; (B) the GBRWHA relative to Australia; and (C) extent of the GBRWHA relative to the west coast of the United States. 7

Figure 1.2  Chapter structure of this thesis. 15

Figure 2.1  The name and spatial location of the 35 mainland drainage basins of the GBRWHA catchment. Major regional centres are underlined. 21

Figure 2.2  Activities guide for zones within the GBRWHA marine parks. © Commonwealth of Australia (July 2004). 26

Figure 2.3  The Australian Government’s Great Barrier Reef Marine Park Zoning Plan and Queensland’s contiguous Great Barrier Reef Coast Marine Park Zoning Plan. 27

Figure 2.4  Dugongs are distributed in the coastal waters of northern Australia between Moreton Bay and Shark Bay. The extent of dugong aerial surveys is shown in red and blue. 31

Figure 2.5  Location of Dugong Protection Areas in the southern GBRWHA and Hervey Bay, Queensland. 33

Figure 3.1  The GBRWHA is divisible into four distinct sections based on their biophysical attributes, as illustrated: Northern GBR, Wet Tropics, Dry Tropics and Southern GBR. The four sections referred to in this study are not the four geo-political management regions that are stipulated in the Great Barrier Reef Marine Park Zoning Plan 1975. The region shaded in red is the extent of coastal waters to approximately -15 m below mean sea level. 40

Figure 3.2  Bayesian belief network for coastal seagrass habitats (Seagrass: present and absent) in the GBRWHA. Predictor variable nodes and their discrete states included: season (Season: wet and dry); section (Section: Northern GBR, Wet Tropics, Dry Tropics, Southern GBR); relative wave exposure (REI: high, medium and low); sea surface temperature (SST: high, medium and low); substrate (SedBasin: present and absent); spatial extent of flood plumes (Rivers: present and absent); tidal range (Tides; high, medium and low); and bathymetry (Bathymetry: high, medium and low). 47

Figure 3.3  Sensitivity of coastal seagrass habitat presence to changes in individual nodes of the Bayesian belief network (Figure 3.2). Predictor variable nodes included: season (Season); section (Section); relative wave exposure (REI); sea surface temperature (SST); substrate (SedBasin); spatial extent of flood plumes (Rivers); tidal range (Tides); and bathymetry (Bathymetry). The bars represent the range of variation in the seagrass nodal variable when values for the states in each predictor variable node were varied over their possible ranges, and all other nodes were held constant at their most likely value. 48
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 3.4</td>
<td>Habitat suitability maps of coastal seagrass distribution in the wet (A) and dry (B) seasons in the remote Cape York region.</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Habitat suitability maps of coastal seagrass distribution in the wet (A) and dry (B) seasons along the urban coast.</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Dendogram showing the two major clusters of survey respondents, their institutional affiliation and gender. GM = government management agency; GR = government research agency; A = academic institution; M = male; and F = female.</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Clusters of planning units of low (cumulative score &lt; 21.3), medium (21.3 – 37.0) and high relative impact (&gt; 37.0) on coastal seagrass habitats in the remote Cape York region.</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Clusters of planning units of low (cumulative score &lt; 21.3), medium (21.3 – 37.0) and high relative impact (&gt; 37.0) on coastal seagrass habitats along the urban coast.</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>Planning units of high, medium and low conservation value to coastal seagrass habitats in the wet (A) and dry (B) seasons within areas of high, medium and low cumulative hazard scores in the remote Cape York region.</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Planning units of high, medium and low conservation value to coastal seagrass habitats in the wet (A) and dry (B) seasons within areas of high, medium and low cumulative hazard scores along the urban coast.</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Extent of dugong aerial surveys (~ 73,000 km(^2)) along the ~2,300 km GBRWHA coastline.</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Dugong semivariogram for the observed aerial survey data and circular model. Distance is measured in kilometres.</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>(A) Model of dugong distribution and relative abundance based on aerial survey data and a kriging interpolation; and (B) the corresponding levels of dugong conservation value in the remote Cape York region.</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>(A) Model of dugong distribution and relative abundance based on aerial survey data and a kriging interpolation; and (B) the corresponding levels of dugong conservation value in the along the urban coast.</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Frequency diagram of dugong relative density derived from a spatially explicit population model. Low conservation values have dugong densities between 0.0015 - 0.25 dugongs/km(^2) (identified in yellow); medium conservation value 0.25 - 0.5 dugongs/km(^2) (blue); and high conservation value &gt; 0.5 dugongs/km(^2) (red).</td>
</tr>
<tr>
<td>Figure 6.1</td>
<td>(A) Model of dugong planning units with high, medium and low dugong conservation value; and, (B) the current risk of bycatch from commercial netting derived from the five levels of netting restrictions relevant to dugongs between Lookout Point and Friendly Point in the remote Cape York region.</td>
</tr>
</tbody>
</table>
Figure 6.2  (A, B) Models of dugong planning units with high, medium and low
dugong conservation value; and, (C, D) the current risk of bycatch from
commercial gill-netting derived from the five levels of netting restrictions
relevant to dugongs along the urban coast. A and C represent the
Shoalwater Bay region, and B and D the region between Cleveland Bay
and Hinchinbrook Island.

Figure 7.1  (A) Model of dugong planning units with high, medium and low
dugong conservation value; and, (B) regions of high and low risk from all
anthropogenic activities between Lookout Point and Friendly Point in the
remote Cape York region.

Figure 7.2  (A, B) Models of dugong planning units with high, medium and low
dugong conservation value; and, (C, D) regions of high and low risk from
all anthropogenic activities along the urban coast. A and C represent the
Shoalwater Bay region, and B and D the region between Cleveland Bay
and Hinchinbrook Island.

Figure 8.1  Priority sites ('hot spots') for coastal seagrass and dugong conservation
action in the (A) remote Cape York region and (B) urban coast.

Figure 8.2  Models of dugong distribution and relative abundance for the region
between Moreton Bay, Queensland and Nhulunbuy, Northern Territory.
Publications produced during my PhD candidature

Publications


Grech, A. and Coles, R. *in prep*. A spatial assessment of the risk to coastal seagrass habitats from multiple anthropogenic threats. Target journal *Aquatic Conservation: Marine and Freshwater Ecosystems*. (Chapter 4)


Grech, A., Marsh, H. and Coles, R. *in prep*. Constraints and opportunities for implementing conservation actions in a multiple-use marine protected area. Target journal *Conservation Biology*. (Chapter 8)


**Reports**

Coles, R., Grech, A., Dew, K., Zeller, B. and McKenzie, L. 2008. *A preliminary report on the adequacy of protection provided to species and benthic habitats in the east coast otter trawl fishery by the current system of closures*. Department of Primary Industries and Fisheries, Brisbane, Australia (52 pp.)


Conference Presentations


