Australian Government
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Marine and Tropical Sciences Research Facility Milestone Report, June 2009

Program 4: **Species and Communities of Conservation Concern**

Project 1.4.1: **Condition, trends and projected futures of marine species of conservation concern**

Project Leader: **Dr Mark Hamann, James Cook University (JCU)**

Report Summary

Objective (a) (Sea turtle nesting success)

A second foraging area training trip was co-run with the Torres Strait Regional Authority (TSRA) and Iama Council in July 2008 with ten Islander participants (see Appendix 2).

Our assessment of genetic structure and juvenile recruitment is close to approaching a sample size of statistical significance (to date ~200 individuals sampled for recruitment and ~105 for genetics). Ninety-four samples have been analysed. Our aim for 2009/2010 is to boost the sample size of samples from adult sized turtles (see Appendix 2).

A third turtle training camp was held in December 2008 to provide training for Torres Strait people in tagging nesting turtles (and Western-based methods) – eight Torres Strait Islanders (TSRA project officers) were trained at the Dowar camp and ten at the Bramble Cay camp (see Appendix 1).

During the nesting season trips, we (1) developed estimates of nesting success for green turtles, and (2) sought to refine data on nest site selection and the thermal variation in the beach. This trip roughly coincided with the Environmental Protection Agency's (EPA) trip to Raine Island. In addition, PhD student Mariana Fuentes conducted a field trip to Milman Island with the support of the EPA to investigate nesting patterns of green turtles.

PhD student John Dawson completed an assessment of beach area and sand volume at Raine Island, concluding that the area has both accretion and erosion zones, but overall the volume of sand has remained similar over time – it is rather the island's beaches that have changed shape.

We have digitised turtle and dugong datasets from the 1970s and 1980s to allow contemporary analysis of hunting patterns using GIS.

Our assessment of the vulnerability of green turtles to climate change is 90% complete and will be completed in the first half of Year 4 (2009/2010). The final remaining step is the risk assessment.

Objective (b) (Communication of project results)

Objective (b) has been completed and final reports delivered in 2008.

Supplementary Objective (Freshwater turtles of the Wet Tropics)

This objective is part of a PhD project by Amanda O'Malley, who has just completed her first year. Although Amanda has completed her proposal and commenced collection of biological data she is yet to undertake her Confirmation of Candidature seminar due to her principal supervisor Dr Ivan Lawler having left James Cook University in December 2008. It took until late February 2009 to gain a new supervisor (Dr Stephen Williams, JCU).

Agreed Project Outputs – June 2009

Report 4 Submission:

- Final report on field work undertaken in Year 2 (2007/2008) to identify aspects of sea turtle nesting success and egg survivorship. The report will build upon results from Year 1 (2006/2007) and include a revised identification and evaluation of key threats (Objective a); and
- Final summary of communication activities undertaken through the course of the project and example of communication products (Objective b).

Project Results

Project 1.4.1 is on track. Objective (a) is approaching completion and Objective (b) is complete. Specific achievements are recorded below.

1. Objective (a) – Milestone Report – Specific Achievements

Climate change

The three-year study on the vulnerability of green turtles in the northern Great Barrier Reef and Torres Strait (PhD project by Mariana Fuentes) is 90% complete. Remaining work includes a climate change risk assessment and analysis of the final year's sand temperature data. Temperature data loggers will remain *in situ* until mid 2010 and then maintenance of loggers will be continued by the Queensland Department of Environment and Resource Management (DERM) (see Appendix 1).

Scientific publications on climate change impacts on green turtles in the northern Great Barrier Reef have been submitted for peer-reviewed publication (see Outputs).

Nesting success

Nesting success varies nightly and across years at each study location. We recorded values between 33% and 80%. Importantly, we did not record nesting success as low as it has been at Raine Island (10%). Hatchling success has been estimated in 2006 at 69% (see Appendix 1).

Juvenile recruitment

Perhaps our most significant finding was that of the 224 green turtles – 186 were juvenile (<65cm) and only ten of these were new recruits to the foraging population (5.3%). This represents a very low level of recruitment for the population. Because new recruits would be around five to ten years of age when they arrive at a foraging area the low level of recruitment we have found may reflect the poor hatchling success at Raine Island since the mid 1990s. This result is also seen in the genetic data which also indicates shifts in the demography of Torres Strait turtles (see Appendix 2).

Raine Island sand loss

PhD student John Dawson has completed a forty-year assessment of beach area and sand volume at Raine Island, concluding that the area has both accretion and erosion zones but overall the volume of sand has remained similar over time. It is the island's beaches that have changed shape.

Genetics and recruitment

Analysis of the genetics of foraging turtles (from sampling commenced under the CRC Reef Research Centre and completed under the Marine and Tropical Sciences Research Facility) were completed by Nancy FitzSimmons and Michael Jensen (The University of Canberra) in Year 2 (94 samples analysed). The data indicate that there could be a decline in the representation from the northern Great Barrier Reef stock and a concurrent increase from other stocks (southern Great Barrier Reef, Gulf of Carpentaria and Indonesia). Answers delivered new questions and we have now expanded our sampling to other sites and analysis is pending. An additional ~100 samples were collected in the 2008 foraging area trip and results are pending.

Historical datasets

We have digitised turtle and dugong datasets from the 1970s and 1980s to allow contemporary analysis of hunting patterns using GIS. The dugong data (completed in August 2008) has been included in a manuscript submitted to *Ecology and Society* (Grayson and others) and the turtle data (completed in February 2009) has been included in a conference abstract (Hess and others) and not yet written up for publication.

Other turtle data sets

Analysis of long-term Queensland Parks and Wildlife Service datasets on green turtles collected from Milman Island has begun (in liaison with Ian Bell, Col Limpus and Milani Chaloupka).

Outputs (chronological) 2008-2009

Peer-reviewed manuscripts
Copies of these 'in review' manuscripts can be made available on request and will be provided to the Marine and Tropical Sciences Research Facility when accepted for publication:
Fuentes, M., Maynard, J., Guinea, M., Bell, I., Werdell, P. J. and Hamann, M. (2009 *In press*) Proxy indicators of sand temperature help project impacts of global warming on sea turtles. *Endangered Species Research* [doi:10.3354/esr00224].
Hamann, M., Grayson, J., Ambar, S. and Marsh, H. (*Submitted*) Ecological benefits arising from community based sea turtle biology and conservation projects. *Wildlife Research* (Submitted March 2009).
Grayson, J., Grech, A., Marsh, H. and Hamann, M. (*In review*) Spatial closures as a practical approach to the management of indigenous hunting: Dugong case study. *Ecology and Society*.
Grayson, J., Hamann, M., Marsh, H. and Ambar, S. (*In review*) Options for managing the sustainable use of green turtles: Perceptions of Hammond Islanders in Torres Strait. *Conservation and Society*.
Fuentes, M., Limpus, C., Hamann, M. and Dawson, J. (*Accepted pending minor revisions*) Community assistance to determine the potential effects of projected sea level rise to marine turtles. *Aquatic Conservation* (Submitted January 2009).
Santana Garcon, J., Grech, A., Moloney, J. and Hamann, M. (2009) Relative Exposure Index: An important factor in sea turtle nesting distribution. *Aquatic Conservation* In press/Early view [doi:10.1002/aqc.1057]
Hamann, M. (2009) Creating community collaborations. Invited editorial. *Marine Turtle*

Newsletter 123: 1-2.
Fuentes, M. M. P. B. and Hamann, M. (2009) A rebuttal to the claim natural beaches confer fitness benefits to nesting marine turtles. *Biology Letters* 5: 266-267 [doi:10.1098/rsbl.2008.0596].
Dryden, J., Grech, A., Moloney, J. and Hamann, M. (2008) Rezoning of the Great Barrier Reef World Heritage Area: Does it afford greater protection for marine turtles. *Wildlife Research* 35(5): 477-485 [doi:10.1071/WR07087]
Conference presentations
Fuentes, M., Limpus, C., Hamann, M. and Moloney, J. (2009) Assessing the vulnerability of key sea turtle rookeries to predicted geographic shifts in cyclone activity. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation – Runner up Student Awards.
Fuentes, M., Limpus, C., Hamann, M. and Dawson, J. (2009) Community assistance to determine the potential effects of projected sea level rise to marine turtles. 29th Symposium on Sea Turtle Biology and Conservation. Poster Presentation.
Grayson, J., Hamann, M., Marsh, H. and Ambar, S. (2009) A toolbox of tools for managing the Torres Strait green turtle fishery. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation.
Hess, L., Hamann, M., Kwan, D. and Grayson, J. (2009) Reassessment of the historical distribution of green turtle hunting by Papua New Guinean kiwai hunters in Torres Strait. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation.
Hamann, M. and Fuentes, M. (2009) Raine island: Issues and implications. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation.
Jensen, M., FitzSimmons, N., Hamann, M., David, C., Ambar, S. and Bell, I. (2009) New insights into the composition of green turtle feeding grounds in the northern Great Barrier Reef. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation
Weiss, K. (2009) Combining indigenous and scientific knowledge to manage migratory marine species across scales: Challenges and opportunities. 29th Symposium on Sea Turtle Biology and Conservation. Oral Presentation.

Schedule of field activities conducted in 2008/2009

Site	Details
Mer (Murray Island)	**Field trip 1:** 23 November – 28 December 2008 (Completed – see Appendix 1) **Field trip 2:** Was planned for late January / early February 2009 however trip was cancelled due to issues with the Torres Strait airline dispute and aircraft availability.
Raine Island and Moulter Cay (QDERM co-investment)	**Field trip 1:** December 2008 (Completed – QDERM ran a trip to Raine Island and Moulter Cay over ten days in December. On this trip they continued the long-term turtle project). Field trip 2: QDERM trip was planned for February 2009 however was cancelled mid-route due to inclement weather.
Milman Island	**Field trip 1:** Late January 2009 (in cooperation with QPWS) (Completed – on this trip staff collected biological data on nesting green turtles, including nesting success of female green turtles, downloaded and re-deployed temperature transmitters to measure the incubation regime for green turtle nests)

Site	Details
Bramble Cay	**Field trip 1:** 30 November – 2 December 2008 (Completed – on this trip staff downloaded and re-deployed temperature transmitters to measure the incubation regime for green turtle nests, and trained TSRA turtle and dugong project staff)
Tudu Cay – foraging turtle trip to assess recruitment	**Field trip 1:** July 2008 (Completed – see Appendix 2)

Proposed schedule of training events for Murray Island Indigenous participants

We will run a community liaison trip to Erub, Mer and Iama in Year 4 (2009/2010), where we will present and explain the results of our work and seek opportunities to continue our work with members of the TSRA turtle and dugong project. In addition, we will seek advice and expertise from islanders about traditional turtle monitoring techniques.

Aspects will cover:

- Turtle tagging and measuring results;
- Beach morphology survey results;
- Assessing the success of turtle nests to produce hatchlings; and
- Beach temperature profile results.

Strategic planning for turtle monitoring in Torres Strait

Since the inception of the TSRA's turtle and dugong project in late 2008 (through *Working on Country*) we have been working with them to develop a specific training plan/manual which spells out a monitoring project for the TSRA turtle and dugong project in Torres Strait.

2. Objective (b) – Milestone Report

Report completed – see Project 1.4.1 webpage for available milestone reports.

3. Supplementary Objective – Progress Report – Freshwater turtles in the Wet Tropics

Amanda O'Malley has completed six months' field work on the project. She has now collected baseline data on *Elseya stirlingi* in the Johnson River Catchment, completed her training in laparoscopy with QDERM, and has begun to assess population structure.

Project problems and opportunities

Objective (a): We experienced difficulties with respect to the availability of aircraft for our December 2008 and February 2009 trips into Torres Strait. The result was that we had to travel a week earlier than expected. The upside was that Mariana Fuentes was able to travel out to Bramble Cay during the peak turtle nesting time and expanded data collection for that Cay.

The January/February 2009 trip had to be cancelled because there was still uncertainty regarding flights to outer islands and charter operations were not available.

Communications, major activities and events

- **Liaison** with Dr Mark Read and Roger Beedon (Great Barrier Reef Marine Park Authority) is regular (bi-monthly) and ongoing.
- **Liaison** with Dr Colin Limpus (QDERM) is regular (~fortnightly) and ongoing.
- **Participation** in the QDERM/GBRMPA Raine Island Research and Management Committee meeting occurs twice per year.
- **Liaison** with TSRA staff (Frank Loban and Damian Miley) is regular (~weekly) and ongoing. In addition, phone discussions with Charles David (Iama) and Moses Wailu (Mer) are conducted regularly (~fortnightly).
- **Participation** in the MTSRF Great Barrier Reef and Torres Strait Operations Committees occurs at least twice each year for each committee.
- **Objective (a):** 1) Climate data collection will be completed. While the bulk of the climate change project was completed in Year 3. We will leave the temperature loggers in place until early 2010 to increase data quality. Upon completion of the project we are negotiating with QDERM and the Torres Strait communities that they will continue to maintain the data-loggers for two to three years to reach a minimum of five years of complete data for each site; 2) We will complete the purchase and analysis of satellite imagery for Raine Island and other island rookeries of the northern Great Barrier Reef and Torres Strait; 3) Long-term QPWS datasets on green turtles collected from Milman Island will be completed (in Liaison with Ian Bell, Col Limpus and Milani Chaloupka); 4) A community feedback trip is planned for Mer, Erub and Iama for Year 4 (we are negotiating the timing with TSRA and community based project officers – the model may include one or two trips). We anticipate beginning the trips within the next reporting period; and 5) A third foraging area trip is tentatively planned for mid 2009 at Mabuiag (note – it may occur after the first milestone in Year 4). On this trip we expect to complete our assessment of juvenile recruitment (aim for ~100 turtles).
- **Supplementary objective (Freshwater turtles in the Wet Tropics):** During the next milestone period Amanda O'Malley will complete her Confirmation of Candidature and continue her field work phase. In particular she will start the climate change aspects of the project by monitoring water temperatures and turtle movement.

Appendices

Appendix 1: Results of turtle tagging trips to Mer (Dowar Island) and Bramble Cay, 2006-2009

Background

The islands in the Mer group (Mer, Dowar and Waer Islands) and Bramble Cay are the most significant green turtle rookeries in Torres Strait (TS) and are main sites for the TS/northern Great Barrier Reef (GBR) genetic population. While there are long-term data sets for the rookeries in the GBR, little quantitative data exists for turtle rookeries in TS (Limpus *et al*. 2001; 2003). In December 2008 we conducted our third annual nesting turtle trip to Dowar Island and our second nesting turtle trip to Bramble Cay. This report deals with the results from these two field trips and results are discussed in relation to data from 2006 and 2007.

QDERM collected complimentary data from Raine Island and Moulter Cay and this data is still being analysed and is thus not presented. These data are being compiled by QDERM and will be made available once QDERM has them cleared for distribution.

In December 2008, Project 1.4.1 (Objective b) undertook studies:

- To determine the patterns, rates and causes of sand loss from Raine Island;
- To calculate reproductive parameters for nesting green turtles at Raine Island, Moulter Cay, Dowar Island and Bramble Cay (size range, nesting success, mortality rates [of nesting turtles], egg production); and
- To determine factors influencing nesting success of sea turtles.

Methods

<u>Patterns rates and causes of sand loss from Raine Island</u>

In 2007 John Dawson (JCU PhD student) used RTK GPS to collect data to map the geomorphology of Raine Island. He then compared his 2007 dataset to the historical data sets on island geomorphology that were made available him by previous researchers.

<u>Turtle nesting surveys</u>

Turtle nesting surveys were conducted on Dowar Island and Bramble Cay and these surveys followed the methods of the QPWS turtle conservation project and those used in 2006 and 2007. As in previous years, tagging data will be entered into the QPWS State-wide relational database. At the end of the night a track count was conducted on at least two of the three beaches at Dowar to determine the number of turtles that had emerged for the night. Two independent observers completed track counts and the average of the two counts was used. This number is likely to be an underestimate because turtles arriving later in the night covered some tracks.

<u>Clutch disturbance</u>

We calculated the clutch equivalent egg mortality using the methods of Limpus *et al.* (2003). In short, CEEM = (egg mortality per clutch disturbed * clutch disturbance)/mean clutch size.

<u>Temperature monitoring</u>

Sand temperature data loggers have been deployed at:

- Dowar (three beaches);
- Bramble Cay;
- Hammond Island (north beach) (not downloaded yet);
- Raine Island;

- Milman Island;
- Sand bank7;
- Sandbank 8; and
- Green Island (not downloaded yet).

Sand temperature was recorded every hour at the study sites from January 2007 to January 2009 (sampling period varied between sites – see Table 1) using Tinytag TK-4014 data loggers (Hasting Data Loggers, Port Macquarie, Australia). All data loggers were calibrated against a mercury thermometer and have an accuracy of ± 0.1°C. Data loggers were located in representative nesting areas and deployed at a standard depth of fifty centimetres. The number of data loggers deployed at each rookery varied in accordance to the variety of nesting habitat present at each site (e.g. shaded and open areas, different beach orientation).

In addition, air temperature data loggers have been deployed at Dowar Island, Bramble Cay, Milman Island and Sandbank 7. Water temperature data loggers have been deployed at Dowar Island. Air temperatures at sights for we had no air temperature loggers were obtained through remote sensed data – International Comprehensive Ocean Atmosphere Data Sets (ICOADS) (http://www.cdc.noaa.gov/coads). Sea surface temperatures were obtained through remote sensing records because data from our water temperature logger at Dowar was found not to be reliable. Reconstructed sand temperatures were determined by modelling the relationship between air temperatures, sand temperatures and sea surface temperatures (paper describing the model has been submitted – Fuentes *et al.* manuscript submitted to *Endangered Species Research*).

Beach profiles

We conducted beach elevation profiles at Dowar Island and Bramble Cay using standard survey techniques.

Results

Raine Island

Patterns rates and causes of sand loss from Raine Island

John Dawson's work has concluded that the area has both accretion and erosion zones but overall the volume of sand has remained similar over time. It is the island's beaches that have changed shape. The erosion zones are on the northeast and northwest corners of the island.

Nesting turtles

Number of turtles nesting per night

In December of 2006, 2007 and 2008 we monitored the three nesting beaches on Dowar Island (one of the three islands in the Mer group) and Bramble Cay. This period coincided with QPWS surveys to Raine Island, Moulter Cay and Sandbanks 7 and 8. At all locations we only recorded nesting by green turtles. The annual variation matches variation in other green turtles rookeries along the Queensland coast:

Average number per night 2006 800
Average number per night 2007 10
Average number per night 2008 250

Average number per night 2007 (Bramble Cay) 9
Average number per night 2008 (Bramble Cay) 216

Nesting success of females

The overall nesting success at Dowar Island and Bramble Cay during 2008/2009 (percentage of female turtles that emerge each night the lay eggs) was 60% and 50% respectively. This compared to 33% and 62% in December 2006 and 2007 respectively (beaches combined). See Tables 1 to 3 for the variation on nesting success at Dowar Island.

Table 1: Nightly nesting success for green turtles nesting on the southern beach of Dowar Island in December 2006 and February 2007.

Date	Beach name	Number of turtles	Number of successful nests laid	Nesting success %
29 Nov 2006	South	109	24 (22%)	22
29 Nov 2006	West	75	8 (10%	10
30 Nov 2006	South	92	22 (24%)	24
30 Nov 2006	West	52	5 (10%)	10
1 Dec 2006	South	108	52 (48%)	48
1 Dec 2006	West	37	5 (13%)	13
2 Dec 2006	South	176	41 (23%)	23
2 Dec 2006	West	51	10 (20%)	20
4 Dec 2006	South	140	62 (44%)	44
29 Jan 2007	South	62	25 (40%)	40
20 Jan 2007	South	42	24 (57%)	57
31 Jan 2007	South	70	38 (54%)	54
1 Feb 2007	South	51	35 (68%)	68
2 Feb 2007	West	39	3 (7%)	7
3 Feb 2007	South	61	34 (56%)	56
MEAN	SOUTH			44%
MEAN	ALL			33%

Table 2: Number of female turtles emerging to nest each night on Dowar Island in 2007.

Date	Beach	Number of turtles	Number of nests laid	% nest success
30 Nov 2007	South	0	0	-
	North	3	2	66
	West	0	0	-
1 Dec 2007	South	0	0	-
	North	3	2	66
	West	0	0	-
2 Dec 2007	South	1	1	100
	North	6	2	33
	West	0	0	-
3 Dec2007	South	0	0	-
	North	7	5	71

Date	Beach	Number of turtles	Number of nests laid	% nest success
	West	0	0	-
4 Dec 2007	South	0	0	-
	North	4	2	50
	West	0	0	-
5 Dec 2007	South	0	0	-
	North	6	3	50
	West	0	0	-
6 Dec 2007	South	0	0	-
	North	5	3	60
MEAN	NORTH			57
MEAN	ALL			62

Table 3: Number of female turtles emerging to nest each night on Dowar Island in 2008.

Date	Beach	Number of turtles tagged	Number of nests laid	% nest success
23 Nov	South	23	13	56
24 Nov	South	30	-	-
	North	25	20	80
25 Nov	South	10	7	70
	North	24	-	-
26 Nov	South	26	4	15
	North	74	61	82
27 Nov	North	55	-	-
MEAN	SOUTH			47
MEAN	NORTH			81
MEAN	ALL			60

Size of nesting female turtles

Dowar Island

The mean size of female green turtles in 2006 was 104.2 ± 5.0cm in December and 102.2 ± 4.7cm in February. The mean size of nesting females from both surveys in 2006/2007 is 103.9 ± 5.0 cm.

The mean size of female green turtles in 2007 was 102.7cm ± 2.8 (n=10).

The mean size of female green turtles in 2008 was 103.6cm ± 4.13 (n=259).

Bramble Cay

The mean size of female green turtles nesting at Bramble Cay in 2007 was 108.0cm ± 4.5 (n=22).

The mean size of female green turtles nesting at Bramble Cay in 2007 was 104.6cm ± 5.1 (n=224)

With the exception of the 2007 data from Bramble Cay these means are each statistically smaller than turtles recorded nesting at Bramble Cay in 1979 (Limpus *et al.* 2001). Furthermore, the means at Dowar in each of the years, and Bramble Cay in 2008 are lower than most seasonal means recorded at Raine Island between 1976 and 2001 (Limpus *et al.* 2003).

<u>Nest excavation</u>

Twenty-five nests were excavated at Dowar Island in 2006 only. No emerging nests were found in 2007 and in 2008 our hatchling season trips were cancelled due to a lack of flights. The mean emergence success in 2006/2007 was 64.6 ± 32.8% (range 0 to 98.8). However, preliminary data indicate that inter- and intra- beach variation is likely (Figure 1). n = 2 (East open light). n = 9 (south open light), n = 8 (south shade dark) and n = 6 (west open dark).

<u>Migration recaptures</u>

In 2008 we recaptured two turtles that were tagged as part of another turtle tagging project. One female was tagged while nesting at Milman Island in 2001. This represents in inter-annual change of rookery of ~150km. The second turtle was tagged by QDERM researchers in the northern GBR during a foraging area trip.

<u>Clutch disturbance</u>

In 2007 and 2008 negligible clutch disturbance (<1% of clutches laid were disturbed by other nesting turtles) was recorded at either Dowar Island or Bramble Cay.

<u>Egg and hatchling predation</u>

Unlike 2006 and 2007, in 2008 at Dowar Island we witnessed predation of one clutch of incubating eggs by goannas (*Varanus indicus*).

<u>Climate change (temperature)</u>

Data loggers have been deployed for various intervals from 2006/2007. Sand temperature was significantly different across the various rookeries (One way ANOVA, $p < 0.00$, df = 11, f = 221.888), with the west facing beach at Milman Island having the coolest temperatures and the north facing beach at Dowar Island having the warmest temperatures. The thermal profile during indicates that Bramble Cay, north (open and shaded) and south (open) Dowar Island, North Milman, East Milman, Moulter Cay, Raine Island, Sandbank 8 are producing mainly female hatchlings. In contrast, the west facing beach at Milman Island is producing mainly males. Both males and females are produced at the other rookeries. However, a female bias occurs with this sea turtle population as the majority of rookeries – including the two most important rookeries for this population (Raine Island and Moulter Cay) – are producing mainly females.

We modelled sand temperatures over the past 18 years and there have been no changes in the mean monthly nest temperature at Bramble Cay, Milman Island and Moulter Cay (Regression, $p = 0.48$, $r = 0.076$, $F = 0.49$; $p = 0.76$, $r = 0.03$, $F = 0.09$; $p = 0.82$, $r = 0.025$, $F = 0.049$; respectively).

With projected increases in air and sea surface temperatures, sand temperatures will rise and cause a reduction in the production of male hatchlings. By 2030, under a conservative scenario of global warming some males will be produced at the shaded areas at South Dowar Island and north Milman Island, south and west Milman Island and Sandbank 7 and under an extreme scenario males will only be produced at west Milman Island and south Sandbank 7. By 2070, under a conservative scenario only the later two rookeries will experience temperatures that produce males and under an extreme scenario no rookery will produce male hatchlings. Increase in temperature will also reduce hatching success for this sea turtle population. Under an extreme scenario, by 2030 the northern facing beaches at north Dowar and Milman Islands will regularly incubate at temperatures above the maximum thermal threshold. By 2070, under an extreme scenario only west Milman Island, Raine Island and Sandbank 7 will not experience temperatures known to cause deformed hatchlings and severe mortality (Table 4).

Table 4: Current and projected sand temperatures during the nesting season at each rookery under conservation and extreme climate change scenarios for 2030 and 2070 (*As published in Fuentes *et al.* 2009).

Site	Environment	Mean sand temperature (°C) during nesting season (November to April)				
		Current	2030 Conservative	2030 Extreme	2070 Conservative	2070 Extreme
*Bramble Cay	North – open	31.6 ± 0.09	32.4 ± 0.210	32.9 ± 0.210	33.6 ± 0.300	35.2 ± 0.300
Dowar Island	North – open	32.6 ± 0.009	33.1 ± 0.070	33.4 ± 0.070	33.6 ± 0.070	34.4 ± 0.070
Dowar Island	North – shade	31.1 ± 0.008	31.7 ± 0.080	31.8 ± 0.080	32.1 ± 0.080	32.6 ± 0.080
Dowar Island	South – open	31.1 ± 0.010	31.6 ± 0.220	32.2 ± 0.220	32.3 ± 0.220	34.0 ± 0.220
Dowar Island	South – shade	30.3 ± 0.090	30.9 ± 0.160	31.4 ± 0.160	31.5 ± 0.160	33.0 ± 0.160
Milman Island	North – open	31.9 ± 0.050	32.2 ± 0.040	32.7 ± 0.040	33.3 ± 0.04	34.7 ± 0.020
Milman Island	North – shade	30.5 ± 0.010	30.9 ± 0.030	31.3 ± 0.030	31.7 ± 0.03	32.9 ± 0.040
Milman Island	East – open	30.9 ± 0.030	31.6 ± 0.030	31.7 ± 0.030	32.2 ± 0.030	33.6 ± 0.030
*Milman Island	South – open	29.8 ± 0.04	30.8 ± 0.031	31.6 ± 0.031	32.4 ± 0.031	34.5 ± 0.031
Milman Island	West – open	28.4 ± 0.010	29.3 ± 0.030	30.2 ± 0.020	30.9 ± 0.030	31.45 ± 0.02
*Moulter Cay	North – open	30.9 ± 0.060	31.7 ± 0.010	32.2 ± 0.010	32.7 ± 0.020	34.2 ± 0.020
Raine Island	Open	30.7 ± 0.040	31.1 ± 0.250	31.3 ± 0.250	31.6 ± 0.250	32.3 ± 0.250
Sandbank 8	North – open	31.5 ± 0.070	31.8 ± 0.300	32.0 ± 0.300	32.3 ± 0.300	33.1 ± 0.300
Sandbank 7	North – open	30.7 ± 0.050	30.9 ± 0.370	31.1 ± 0.370	31.5 ± 0.370	32.4 ± 0.370
Sandbank 7	South – open	30.2 ± 0.070	30.3 ± 0.280	30.5 ± 0.280	30.8 ± 0.280	31.5 ± 0.280

Beach profile mapping

Beach profile data was collected and alalysed from Bramble Cay, Dowar Island and Milman Island. Projected sea level rise (SLR) is expected to cause shoreline erosion, saline intrusion into the water table and inundation and flooding of beaches and coastal areas. To understand current threats and to quantify future impacts to green turtles of the northern GBR and Torres Strait we investigated how sea level rise might affect key nesting grounds (n= 8) (rookeries) utilised by the northern Great Barrier Reef green turtle population (nGBR), the largest green turtle population in the world. To provide insights into the extent into which the reproductive output of each rookery could be affected under a range of SLR scenarios we developed 3-D elevation models and applied sea level rise (SLR) scenarios projected by the IPCC 2007. Results indicate that up to 38% of available nesting area across all the rookeries may be inundated as a result of SLR (Figure 1). Flooding will potentially increase egg mortality and loss of nesting area at these rookeries, affecting the overall reproductive success of the nGBR green turtle population. Reduction of available nesting area will also amplify density-dependent issues at nesting grounds. Rookery vulnerability varied greatly, with Sandbank 7, MacLennan Cay, western Dowar, Sandbank 8 and Milman Island being the most vulnerable rookeries, of those rookeries investigated, in order of vulnerability. Impacts by inundation, will be less severe at rookeries with elevated sand dunes, such as at northern Dowar (Figure 2).

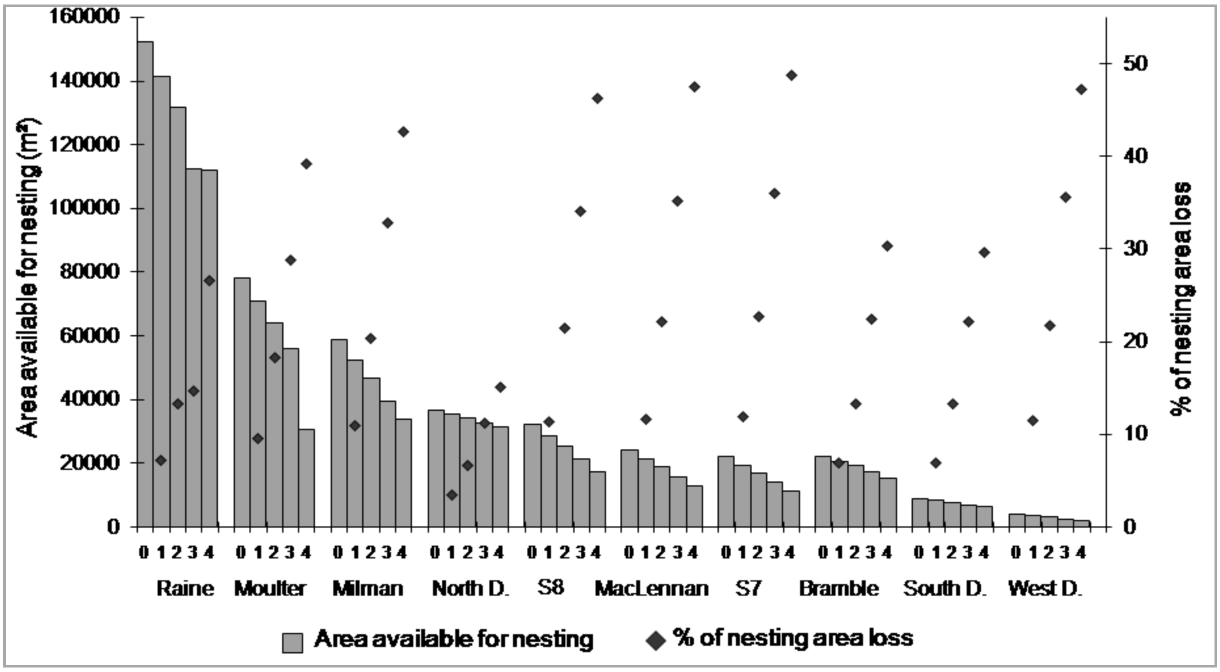

Figure 1: Area available for nesting at each rookery for the northern Great Barrier Reef and Torres Strait green turtle population and percentage of area predicted to be lost under each scenario. [0 = current, 1 = Scenario 1 (0.18m), 2 = Scenario 2 (0.35m), 3 = Scenario 3 (0.59m), 4 = Scenario 4 (0.79m).

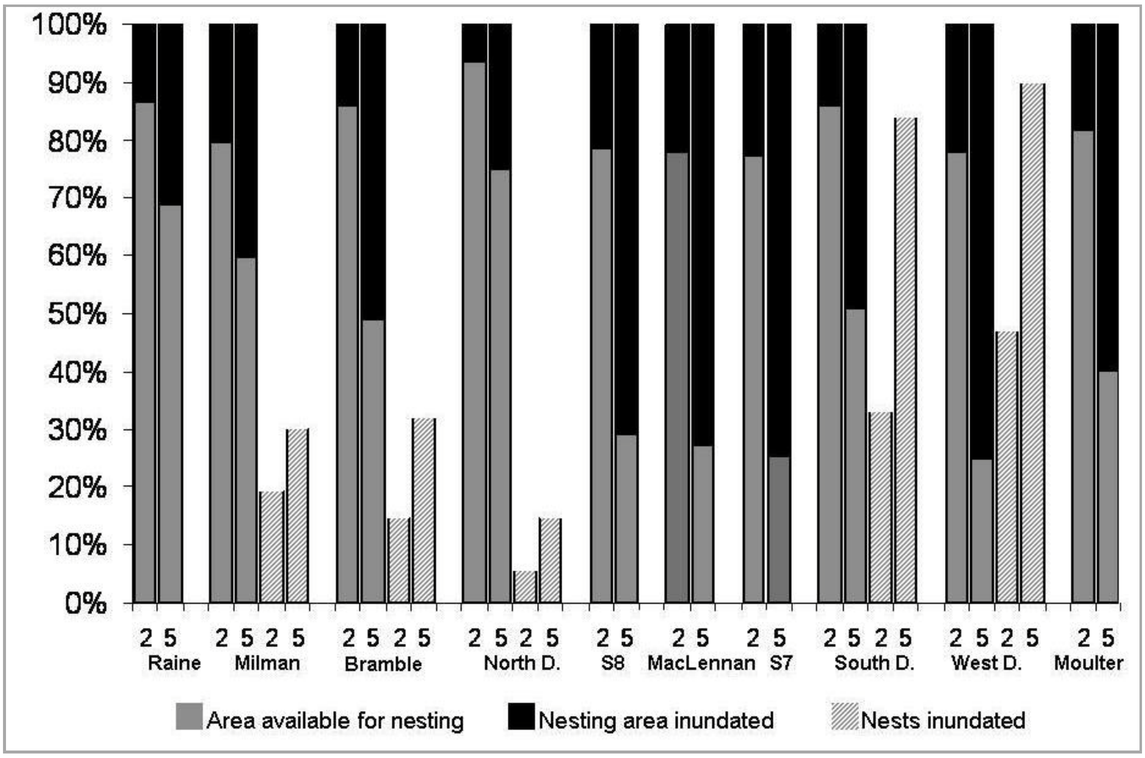

Figure 2: Percentage of nesting area and nests inundated with an intermediate sea level rise (Scenario 2) and during storm events (Scenario 5) at rookeries for the northern Great Barrier Reef and Torres Strait green turtle population.

Discussion

Biological data

There are seven main rookeries used by turtles of the northern GBR and Torres Strait green turtle population. Regular and semi-regular data exist for four of these rookeries (Raine Island, Moulter Cay and Sandbanks 7 and 8) and a comprehensive assessment is provided in Limpus *et al*. (2003). In addition, there are data from the late 1970s and occasional brief surveys for Bramble Cay (see Limpus *et al*. 2001 and 2003) and green turtle data has been collected opportunistically during hawksbill turtle surveys at Milman Island. The Islands of the Mer group represent the only major 'non coral cay' nesting habitat for the population. This study, starting in 2006, represents the first quantitative assessment of the Dowar Island green turtle rookery.

One of the key threats that have been identified for green turtles in the northern GBR and Torres Strait population is poor ability of females to dig nesting sites and successfully lay eggs. Indeed at Raine Island the percent nesting success if generally very low in years with above average numbers of females breeding and in recent years has been regularly less than ten percent (Limpus *et al*. 2003, Col Limpus pers. comm.), even in late season nesting and in nights following rainfall (QPWS unpublished data and Mark Hamann pers. obs.). In 2006/2007, and again in 2008/2009, we recorded variable nesting success among the two of the three beaches at Dowar Island. At the southern beach we recorded low nesting success in December (32% in 2006 and 50-60% in 2008) and this increased to 55% in February (2006 only) once regular nightly rainfall had begun and the number of females ashore each night had declined. In 2007 nesting success was 62%, which most likely reflects the smaller and less dense nesting aggregations. At Bramble Cay nesting success was similar in 2007 (64%) and 2008 (50%) and both years were similar to data from the 1970s (Limpus *et al*. 2001).

Future directions should include:

- Examining nest site selection (using Dowar and Milman Island data);
- Modelling of green turtle trend data using Milman Island as an index site;
- Sediment budgets (Raine Island and Bramble Cay);
- Examination of recruitment (all sites);
- Hatchling production (as many sites as possible); and
- Examining juvenile recruitment.

Climate change

Beach temperatures

Sand temperature varied greatly between and within the nesting grounds used by the northern GBR green turtle population, with open areas in the sand dune at northern facing beaches being the warmest incubating environments. North-facing beaches receive more solar radiation than beaches at other orientations and consequently are warmer. Variation in intra and inter-beach sand temperature ensures that eggs are incubated within a wider thermal range and both male and female hatchlings are produced to sustain turtle populations. Even though, the nesting grounds used by the northern GBR green turtle population experience both male and female producing temperatures our results suggests a bias towards female hatchling production into this population. Indeed, a female bias has been commonly reported for different sea turtle species and nesting grounds with populations appearing to function successfully with 1:2 or 1:3 male to female ratio (Hamann *et al.* 2007). It is not known what sex ratio can be sustained long term. Ratios above one male to four females that persist for more than a generation may not sustain sea turtle populations (Hamann *et al.* 2007).

Beach profiles and sea level rise

The results from this study indicate that, (a) the most vulnerable rookeries to sea level rise are those with lower elevations, and (b) that nests at higher risk from inundation are those laid closer to HWM. Considering this, Sandbank 7, MacLennan Cay, west Dowar, Sandbank 8 and Milman Island should be the most vulnerable rookeries, in order of vulnerability, and nests laid at these sites, as well as at south Dowar, will potentially suffer the greatest impact by sea level rise.

Impacts by inundation will be less severe at rookeries with elevated sand dunes (Limpus 2006), such as at North Dowar. Flooding caused by sea level rise will potentially increase egg mortality and loss of nesting area at these rookeries, affecting the overall reproductive success of the northern Great Barrier Reef green turtle population.

Reduction of available nesting area will amplify density-dependent issues at nesting grounds, possibly increasing nest disease and destruction of nests by co-specifics. The latter already occurs at Raine Island, Moulter Cay, Dowar and Bramble Cay, especially during high-density nesting years. Higher nesting density at a particular rookery may also reduce clutch production as repetitive disturbance by co-specifics can result in premature use of somatic energy stores and resorption of ovarian follicles. Another outcome of sea level rise will be an increased impact to nests and nesting area during storm events, primarily due to waves penetrating even further inland during storms as a result of higher than normal tides from sea level rise. The most significant increase in nest inundation will occur at west and south Dowar, where nest inundation rises from 47-90% and 33-84% respectively during storm events.

Future directions should include:

- Examining factors that determine nest site selection; and
- Determining the adaptive capacity and resilience to sea level rise such as moving nests back further into the dunes.

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Appendix 2: Tudu summary

To continue the assessment of recruitment of green turtles to Torres Strait we spent four days catching turtles at Tudu, Dungeness and southern Warrior Reefs. At least three people in each of four boats caught and tagged, measured and took a genetic sample from individual turtles. Each turtle was examined for signs of an individual that had recently recruited to Torres Strait (i.e. sharpened edges to the marginal scutes, distinct plastron ridges, black colouration in the mouth and a lack of epibionts).

2008 Data

Turtle species and numbers

We observed and caught three species (green, hawksbill and loggerhead):

- 5 loggerheads turtles;
- 26 hawksbill turtles; and
- 74 green turtles.

Of the turtles caught, 80% had their sex determined through laparoscopy. The sex ratio for hawksbill turtles was 3F:1M and for green turtles 12F:1M. Of the juvenile green turtles, two (of 64 juveniles) were classed as new recruit turtles to the reef (i.e. they had recently arrived from the ocean, had very clean shells with sharp edges around their carapaces and had dark staining in the mouth from eating oceanic prey. One juvenile green turtle was reported with fibropapilloma and no other turtles had signs of damage or disease. To expand on the genetics project skin samples were collected for a genetic study and data will be analysed later in 2009. Four sand temperature loggers were buried at Tudu to monitor sand temperatures at the cay for one year. These will be collected in July to August 2009.

Turtle recaptures

One adult female loggerhead turtle was caught that had already tagged. Upon reporting the tag numbers to Col Limpus at QPWS he advised that the turtle had been tagged by a group of community volunteers in 2000 at Wreck Rock Beach, near the town of Agnes Waters, roughly 100km north of Bundaberg. This was a successful recapture, as most recaptures of loggerhead turtles occur through fisheries bycatch (i.e. they are dead when retrieved from the water).

Summary of data, 2006-2008

Three species have been captured: 224 green turtles (70.8%), 81 hawksbill turtles (25.6%) and 11 loggerhead turtles (3.5%). The mean turtle catch per hour (CPH) was 2.28 ± 0.16 (range 1.45 to 3.87) and 1.57 ± 0.17 (range 0.72 to 2.84) for green and hawksbill turtles respectively (Table 2). The mean catch per kilometre searched (CPKS) was 0.40 ± 0.03 (range 0.26 to 0.72) and 0.27 ± 0.03 (range 0.05 to 0.48) for green and hawksbill turtles respectively. There was no statistically significant difference between either the catch rates per hour or the catch rates per kilometre of searching between green and hawksbill turtles (Student's T-test; $t = 1.02$; d.f. = 4; $P = 0.18$ and $t = 1.07$; d.f. = 4; $P = 0.17$ respectively). While it is not possible to directly compare across sites, the abundance data found in our study appear to be lower than those reported for Heron Island in the Great Barrier Reef (5-21 individuals km^{-2}) and the reefs around the Sir Edward Pellew islands (5-10 individuals km^{-2}).

Our most significant finding was that of the 224 green turtles, 186 were juvenile (<65cm) and ten of these were new recruits to the foraging population (5.3%). This represents a very low level of recruitment for the population. Because new recruits would be around five to ten years of age when they arrive at a foraging area the low level of recruitment we have found may reflect the poor hatchling success at Raine Island since the mid 1990s. This result is also seen in the genetic data which also indicates shifts in the demography of Torres Strait turtles.

One of the unexpected outcomes of the study was the discovery of green turtle fibropapillomatosis (GTFP) in juvenile green turtles. While there has been little quantitative data published on GTFP rates in Australian green turtle populations, our data indicate that juvenile green turtles have a similar rate of infection to turtles in some coastal bays (e.g. Moreton Bay adjacent to Brisbane have an incidence of 10% and 60% in green turtles depending on specific localities; QPWS unpublished data) and seemingly higher rates than those found in relatively pristine coastal bays (e.g. Incidence in green turtles from Shoalwater Bay 0.5% to 2.12%; (Limpus and Miller 1994; Limpus *et al.* 2005) and reef habitats (e.g. Incidence in green turtles from Heron Reef <1%; QPWS unpublished data). Although initial reports suggested that turtles with GTFP have high mortality rates, recent data suggests that recovery is possible, especially in turtles that are less than severely inflicted (Work *et al.* 2000; Limpus *et al.* 2005). However, once the lesions cover eyes, mouth or become internal, as they did in over fifty percent of the cases we observed, recovery rates are lower (Work *et al.* 2000). There is little evidence to state causes of the disease and we do not have enough data from Torres Strait to make assumptions about habitats where the disease might be more or less prolific or about recovery rates for this population.

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