Australian Government

Department of the Environment and Water Resources

Marine and Tropical Sciences Research Facility (MTSRF)

June 2007 Milestone Report

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

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Note: This report deals with Objective B of Project 1.4.1: To analyse the patterns, rates and causes of sand loss from green turtle rookeries of international significance in the northern Great Barrier Reef region; and to provide an assessment of remote methods of recording human visitation at remote sites of high conservation significance. The effects of various climate change scenarios on sea turtle sex ratios and hatchling survivorship will also be assessed.

Summary

Objective B

1) **Murray Island** – Ten days were spent in early December 2006 collecting data on nesting turtle biology, island geomorphology and sand/air and water temperature loggers were deployed.
2) **Raine Island/Moulter Cay/Sandbanks 7&8** – The EPA funded and ran a field trip to the northern GBR in December 2006. Unfortunately, the timing of the MTSRF contracts did not allow us to enter into a formal agreement for this trip, or participate in the research trip. However, EPA staff collected sand samples for us to analyse as part of a region wide sediment analysis of sea turtle nesting sites. We have developed a project plan that will form the basis a formal partnership between JCU and EPA with regards to Project 1.4.1 (Objective B). The working group, established in November 2006, will meet again on 13 June 2007 to discuss progress and define the relationship between parties.
3) **Milman Island** – Twelve days were spent on Milman Island (northern GBR) collecting data on nesting turtle biology, island geomorphology and sand/air temperature loggers were deployed.
4) **Bramble Cay** – One day was spent on Bramble Cay collecting data on island geomorphology and sand temperature loggers were deployed. The island geomorphology of this site is yet to be completed.

Project Results

1. SCHEDULE OF FIELD ACTIVITIES

1.1 Field trips

Mer (Murray Island)
Field trip 1 – 29 November to 6 December 2006
Field trip 2 – 29 January to 6 February 2007

Raine Island and Moulter Cay (QPWS/EPA co-investment)
Queensland Parks and Wildlife Service ran a trip to Raine Island and Moulter Cay in the first two weeks of December 2006.

Milman Island
11-24 January 2007 (in cooperation with QPWS)

Bramble Cay and Erub (Darnley Island)
20-21 March 2007 (in cooperation with TSRA Land and Sea Management Unit)

1.2 Proposed schedule of training events for Torres Strait Islanders

1.2.1 Nesting beach surveys

We ran our first two field trips to Mer (Murray Island) in early December 2006 and early February 2007. These trips mostly focused on gaining local insights on turtle nesting patterns, turtle beaches and developing relationships with the traditional owners of the nesting beaches (of Dowar Island). On future trips training and capacity building will occur and will address the following topics:

- Turtle tagging and measuring (as per standard methods used in Australia)
- Track counts and the types of information that are important such as the number of turtles that successfully lay each year
- Beach morphology surveys
- Assessing the success of turtle nests to produce hatchlings
- Monitoring of beach temperature profiles.
- Predator exclusion

A specific training plan which spells out expectations, roles and responsibilities is being prepared and will be discussed with the Mer Council and Torres Strait Regional Authority (TSRA) Land and Sea Management Unit before being finalised.

1.2.2 Foraging area surveys

The first training trip is scheduled for June 24 to June 30 2007. On this trip Mark Hamann, Mariana Fuentes (from JCU) and Stephen Ambar (Hammond Island) will conduct training for TSRA staff and turtle and dugong project officers on turtle biology. A specific training plan which spells out expectations, roles and responsibilities is being prepared and will be discussed with the Murray Island Council and Torres Strait Regional Authority (TSRA) Land and Sea Management Unit before being finalized. The training plan is expected to cover

turtle tag application, turtle carapace measurements, identification of "new" recruit turtles, data recording, data accuracy and data storage.

2.   RESULTS OF FIELD BASED RESEARCH

Prepared by Mark Hamann and Mariana Fuentes

2.1 Background

The green turtle population in the northern Great Barrier Reef and Torres Strait (nGBR/TS) is the largest in the world. Based on turtle nesting data collected by Queensland Parks and Wildlife Service since 1976 it is estimated that an average of 50,000 females breed each year in this population (Limpus et al. 2003). Approximately 90% of this occurs on two small sand cays in the northern GBR; Raine Island and Moulter Cay. Other main nesting sites are Bramble Cay and Murray Islands (Mer, Dowar and Waer) in Torres Strait and Milman Island and Sandbanks 7 and 8 in the northern GBR (Figure 1; Limpus et al. 2003). Torres Strait is an important region for this green turtle population because it serves as an important foraging, migratory and courtship area. Under the Native Title Act Torres Strait Islanders are permitted to hunt turtles in their sea country, and results from genetic studies show that ~ 80% of green turtles taken in Torres Strait and southern PNG (Daru) come from the nGBR/TS population. Thus the population has important ecological, social and cultural value.

Although the nesting population has been systematically studied since the mid 1970s there is no evidence of population trends (Limpus et al. 2003). However, in 1996 QPWS data revealed other biological trends that may be indicative of a population in early stages of decline (see Limpus et al. 2003). These indicators include declines in the average size of turtles (carapace length) breeding each year, high recruitment rates and shifts in remigration intervals. Since 1996 another major threat to the nGBR/TS population has emerged – poor hatchling production (Limpus et al. 2003). QPWS service data indicate that nesting success is low (the % of females able to successfully lay eggs each night) and hatchling production is low. Reasons for this are thought to include accelerated erosion of the beach, alterations to the beach rock formation or other geo-morphologic processes. One suggestion is that when the Guano miners were operating on the island in the late 1800s they altered the reef flat to allow easy access and anchorage for their vessels, and now the altered platform is acting as a conduit for sand as it is washed off the beach.

Therefore Project 1.4.1 (Objective B) aimed to:

- To determine the patterns, rates and causes of sand loss from Raine Island, Moulter Cay (GBR) and Murray Island (Torres Strait).
- To calculate reproductive parameters for nesting green turtles at Raine Is, Moulter Cay and Murray Island (size range, recruitment rates, nesting success, mortality rates [of nesting turtles], egg production).
- To determine factors influencing nesting success and hatchling survivorship of sea turtles.
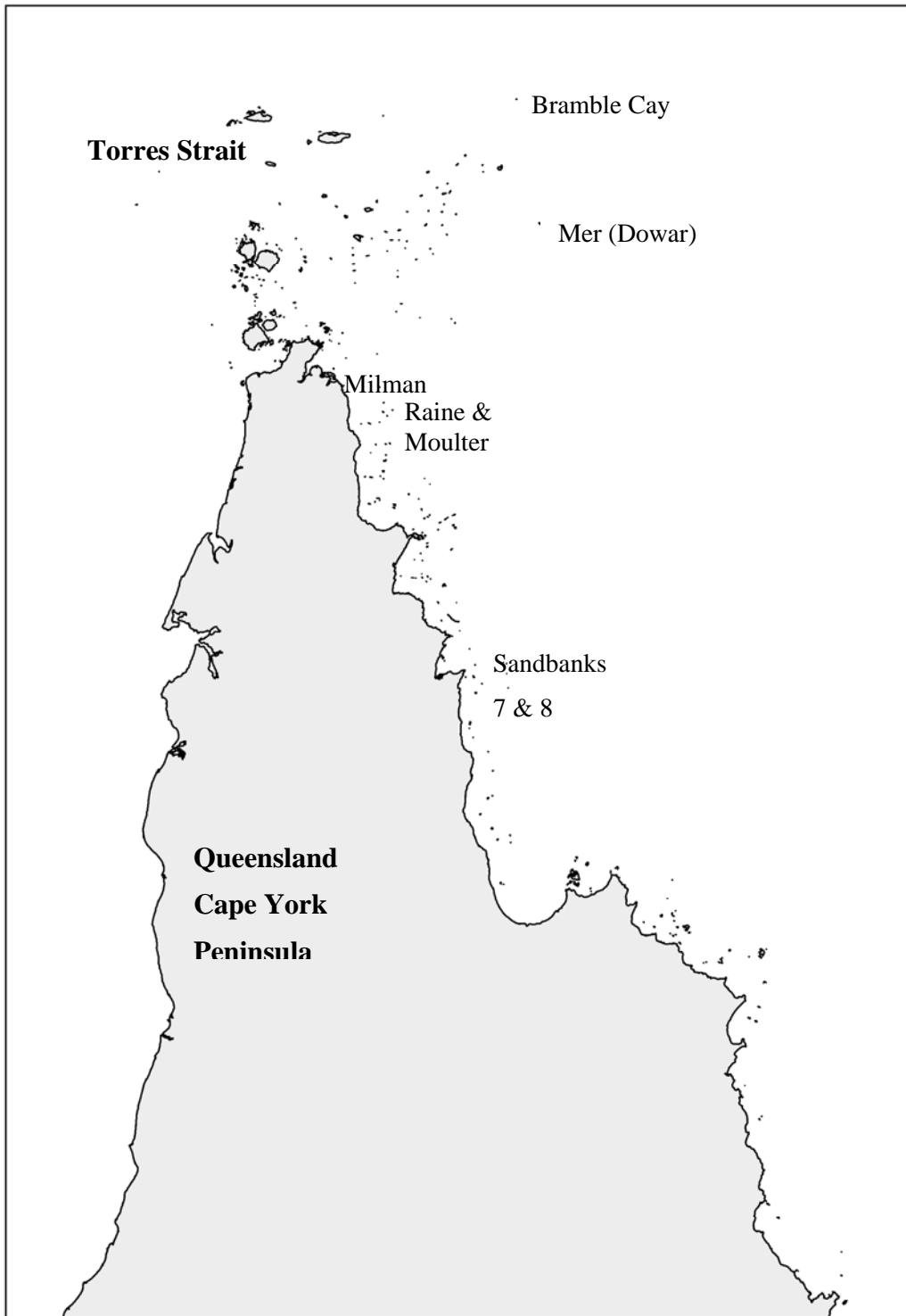- To determine recruitment rates of juvenile turtles into the population.

Figure 1. Location of main green turtle nesting sites in the northern GBR and Torres Strait

2.2 Methods

Turtle nesting surveys

Turtle nesting surveys were conducted on Dowar Island (in the Mer group) and Milman Island in the northern GBR and these surveys followed the methods of the QPWS turtle conservation project. Indeed the green turtle surveys at Milman Island were done in partnership with Ian Bell of QPWS's hawksbill turtle surveys. In short, turtles were approached after nesting and tagged with a single titanium tag in the L3 or R3 position (Limpus 1992) and their curved carapace was measured (Limpus 1985). Nest sites were marked using GPS and the position on the beach was noted (under trees, in grass, sand colour). At Dowar Island 25 nests were mapped out using triangulation to obvious reference points. During nightly turtle tagging patrols the number of clutches disturbed by turtles digging new nests was counted. Tagging data has been entered to 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.

Hatchling production

Hatchling production was assessed at Dowar Island and Milman Island. Because of the large number of turtles digging nests each night at Dowar Island the sheer volume of sand shifted meant that it was not possible to find any of the mapped nests. We discovered turtle nests by either, watching hatchlings emerge or following hatchling tracks back up the beach. We calculated hatchling production following the standard methods of Miller (1999). In short, nests were dug and all contents were removed to the sand surface. Counts were made of empty shells, whole unhatched (obvious embryo) or undeveloped (no obvious embryo) eggs, predated eggs and hatchlings trapped dead or alive in the nest. From these counts we calculated the % of eggs that produced hatchlings to the beach (emergence success). Emergence success data was calculated for 25 nests at Dowar Island.

Clutch disturbance

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.

Temperature monitoring

Sand temperature data loggers have been deployed at:

- Dowar Island - southern (n=4) and northern beach (n=4) two each in shade and open sites. Deployed December 2006 and re-set in Feb 2007
- Bramble Cay – Deployed in March 2007
- Milman Island – Deployed in January 2007
- Sandbank 7 & 8 - Deployed in May 2007
- Moulter Cay – Deployed in May 2007

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.

<u>Beach profiles</u>

We conducted beach elevation profiles at Dowar Island, Milman Island and Bramble Cay (50% complete) using standard survey techniques. QPWS have conducted surveys of Raine Island using RTK GPS.

<u>Sand composition analysis</u>

In partnership with QPWS sand samples were collected (n=2-4) from beach transects (running from the reef flat to the top of the dune). Samples from each transect were representative of each beach zone (reef, toe, berm and cliff), however smaller sites (sandbank 7 and 8) only had two samples collected representing the beach toe and berm. The number of transects differed between sites according to site size (n=3-7). A total of 164 sand samples were collected at representative places across all sites, being 32 from Raine Island, 16 from Moulter Cay, 16 from both Sandbank 7 and 8, 28 from Milman Island, 48 from Dowar Island (3 beaches) and 34 from Bramble Cay. A GPS location was acquired for sample locations for further spatial analysis. Samples were analysed in two stages, which compromises of a textual and compositional analysis, following methods by Dawson (2006).

<u>Sand composition - textual analysis</u>

Textual analysis was used to characterize grain-size distribution. This was achieved by utilising a Rapid Sediment Analyser (RSA), where grain sizes were expressed as Phi (φ) categories based on the equation:

$\Phi = -\log^2 d$, where d= grain size in mm (Krumbein, 1934).

We split dried samples into smaller samples (10- 15g) following methods by Ingram (1971). Sorted and labelled samples were analysed every 10 min in the RSA. The input of each log file, generated by the RSA, was copied into SedRep (Microsoft Excel ® based data reporter developed by the school of Geography and Environmental Science, University of Auckland, New Zealand). SedRep calculated grain statistics, which includes mean grain-size, skewness, kurtosis and a logarithmic 'method of moments', as well as producing a size frequency distribution and cumulative frequency curve based on Folk and Ward (1957).

<u>Sand composition - compositional analysis</u>

Compositional analyses were used to identify the skeletal compositional structure from the study sites. The compositional constituents from samples were examined following the sieve method outlined by Martin and Liddell (1988). Samples were dried sieved into 1.5φ, 1.0 φ, 0.5 φ, 0.0 φ, -0.5 φ and >/ -1.0 φ (0.35, 0.50, 0.71, 1.00, 1.41 and >/2mm) size fractions and then point counted under a binocular microscope using a 'ribbon method' described by Galehouse (1971; p. 391-392) and Dawson (2006). At leat 100 grains were point counted for each sieve fraction whenever possible (e.g. larger or smaller fractions had samples that contained less than 100 points). Each grain was identified using a photographic table produced by Dawson 2006 and classified into 17 recognized component categories (Table 1).

Table 1. List of the skeletal constituent categories identified from carbonate sediments.

Coral	*Baculogypsina sp.*	Alcyonarians spicules
Coralline Algae	*Marginopora vertebralis*	Bryozoans
Bivalves	*Homotrema rubra*	Serpulids
Gastropods	Other Foraminiferans	Crustacean
Undetermined Molluscs	Halimeda	Indeterminate
Amphistegina sp.	Echinoids plates and spines	

The composition of each sample was calculated by multiplying the composition of each portion by the proportion of that fraction to the total sample weight (Smithers 1994, Dawson 2006). The proportion of each size portion to the overall sample weight was acquired from the raw textual data generated by the RSA through the SedRep.

Statistical Analysis

Independent one-way ANOVA was used to investigate the differences of the mean textual and compositional structure at each site in terms of beach zones and orientation. Furthermore, textural and compositional data were analysed separately using Principle Component Analysis (Principal Component and Classification Analysis using Statistica®). The number of factors (principle components) used to explain maximum variance with minimum meaningless information within the datasets (ordination) were decided based on the Kaiser Criterion (Kaiser 1960), where only factors with eigenvalues greater than 1 are included. Over 70% of the variance was explained by all PCA's that were conducted. The factor patterns of identified principle components were then analysed using a hierarchical cluster analysis (joining cluster analysis), based on Ward's (1963) method and Euclidian distances between samples. The cluster analysis groups samples from the reduced principle component space into clusters of the most similar sediments (facies).

2.3 Results

2.3.1 Nesting turtles

Number of turtles nesting per night

In December 2006 we monitored the three nesting beaches on Dowar Island (one of the 3 islands in the Mer group). This period coincided with QPWS surveys to Raine Island, Moulter Cay and Sandbanks 7 & 8. We only recorded nesting by green turtles. The number of turtles recorded per night is provided in Table 1. The average number of turtles per night for South beach were 122 ± 41 in December and 54 ± 9 in February. The average number of turtles per night for west beach were 53 ± 19 in December and 38 ± 14 in February. One night of partial survey (3 December 2006) indicates that in the order of 150 turtles per night were using the north beach. We estimate that 300 to 500 turtles came ashore each night on Dowar Island during early December 2006.

Table 1. The number of female turtles emerging to nest each night on Dowar Island.

Beach	Date	Number of turtles
South beach	29 November 2006	109
West beach	29 November 2006	75
South beach	30 November 2006	92
West beach	30 November 2006	52
South beach	1 December 2006	108
South beach	2 December 2006	176
West beach	3 December 2006	62
North beach*	3 December 2006	64
South beach	4 December 2006	140
South beach	5 December 2006	158
West beach	5 December 2006	68
South beach	29 January 2007	62
West beach	29 January 2007	19
South beach	30 January 2007	42
West beach	30 January 2007	52
South beach	31 January 2007	70
South beach	1 February 2007	51
West beach	1 February 2007	43
West beach	2 February 2007	39
South beach	3 February 2007	61

* indicates partial count

Nesting success of females

We assessed ~75% of turtles ashore for nesting on the southern and western beaches at Dowar Island on for nesting success (i.e. whether they were successful at laying eggs). Overall the average % nesting success for females nesting on the southern beach (n = 5 nights) of Dowar Island was 32% in December and 55% in February, and the nesting success of females on the west beach was 13% in December (n = 4 nights) and 7% in February (1 night) Table 2).

Size of nesting females

At Dowar Island 202 turtles and 41 turtles were tagged and measured in December 2006 and February 2007 respectively. The mean size of females was 104.2 ± 5.0cm in December and 102.2 ± 4.7cm in February. The mean size of nesting females from both surveys combined is 103.9 ± 5.0 cm. These sizes are statistically different (smaller) than turtles recorded nesting at Bramble Cay in 1979 (t-test; T= -4.47; P<0.001) (Limpus et al. 2001). Furthermore, the mean at Dowar in 2006/2007 is lower than any of the seasonal means recorded at Raine Island between 1976 and 2001 (Limpus et al. 2003). Even if the 2006 February data from Dowar Island is excluded the mean recorded at Dowar Island in December is lower than all but one seasonal mean (1996 – 104.1cm) from 1976 to 2001. The data from Dowar is consistent with smaller turtles breeding in high density nesting seasons (Limpus et al. 2003).

Table 2. 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 successful nests laid (% or total females)	Number of females ashore
29 November 2006	South	24 (22%)	109
29 November 2006	West	8 (10%	75
30 November 2006	South	22 (24%)	92
30 November 2006	West	5 (10%)	52
1 December 2006	South	52 (48%)	108
1 December 2006	West	5 (13%)	37
2 December 2006	South	41 (23%)	176
2 December 2006	West	10 (20%)	51
4 December 2006	South	62 (44%)	140
29 January 2007	South	25 (40%)	62
20 January 2007	South	24 (57%)	42
31 January 2007	South	38 (54%)	70
1 February 2007	South	35 (68%)	51
2 February 2007	West	3 (7%)	39
3 February 2007	South	34 (56%)	61

Migration recaptures

We recorded a turtle nesting (K58192) on December 2 2006 at Dowar that was initially tagged in a foraging area study in the northern GBR (QPWS unpublished data). We did not recapture any other turtles that were tagged as part of another turtle tagging project.

Location of nests on beach

We mapped the location of 200 successful nests on the southern beach of Dowar Island in December 2006 to investigate relations between nest location, beach profiles and thermal conditions (e.g. Figure 2). These relationships will be determined as other data sets are analysed.

2.3.2 Hatchling production

Nest excavation

Twenty-five nests were excavated at Dowar Island. The mean emergence success for these nests was $64.6 \pm 32.8\%$ (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).
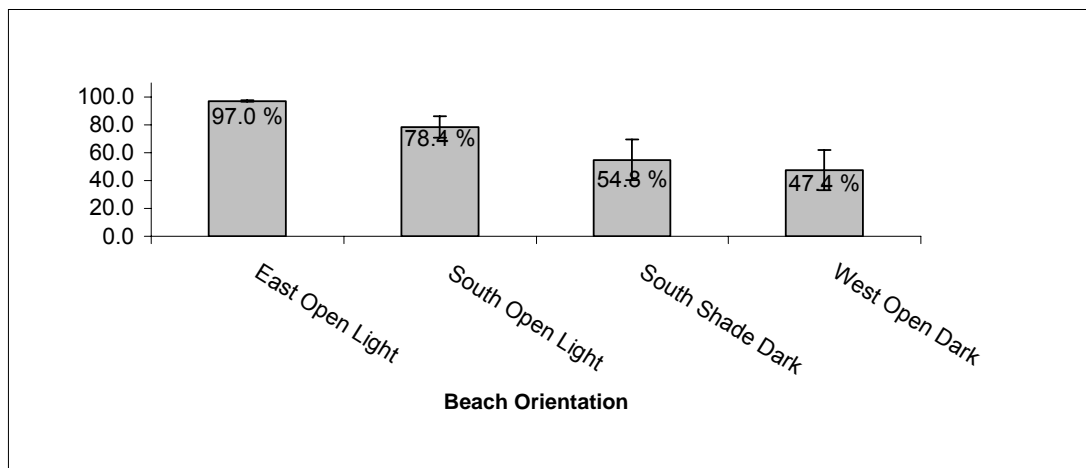
Figure 1. Emergence success (%) data for 25 green turtle nests excavated at Dowar Island in February 2006.

Clutch disturbance

We recorded an average of 4.6 nests per night that were dug into and partially destroyed by nesting turtles. This represented a mean clutch disturbance (clutches disturbed/clutches laid) of 13.6% and a mean egg mortality per disturbed clutch of 14.6 ± 9.0 eggs. The clutch equivalent egg mortality (based on a mean clutch size of 104 eggs per clutch – Limpus et al. 2003) was 0.2%. This is similar to the proportion estimated at Raine Island in high-density nesting seasons (Limpus et al. 2003).

Egg and hatchling predation

At Dowar Island we did not witness any predation of incubating eggs or hatchings from goannas (*Varanus indicus*) despite this species being common on the beach and they are regular predators of incubating turtle eggs at other locations. We did however observe *V. indicus* scavenging on eggs dug up by turtles.

We did not witness any avian predation on turtle hatchlings.

Several small sharks (black and white tip reef sharks) and predatory fish such as trevally were recorded preying on turtle hatchlings over the reef crest. This predation was not quantified.

2.3.3 Climate change (temperature)

Data loggers were deployed between December 2006 and March 2007. The trips to download data will occur between November 2007 and February 2008.

2.3.4 Beach profile mapping

Beach profile data was collected from Bramble Cay (50% complete), Dowar Island (3 beaches) and Milman Island. These data are yet to be analysed.

2.3.5 Sand profiles

At this stage in the project we have completed the analysis of the compositional structure, texture and facies of sand samples collected at Raine Island, Moulter Cay and the two

sandbanks. Analysis of samples collected at Dowar Island, Milman Island and Bramble Cay will be undertaken within the next milestone period.

2.3.5.1 Raine Island

Textual Analysis of Raine Island

The superficial reef sediments collected from Raine Island are predominantly sand-sized (92.9%) and moderately sorted to well sorted. Mud-sized sediments are generally absent. Overall, the majority of sediment from Raine Island is coarse sand (mean 0.31φ), with mean variations of very coarse sand (-0.59 φ) to coarse sand (0.90φ) (Table 3). Grain size distributions of sediments are unimodal giving an overall unimodal distribution with the majority of sediment belonging to the 0.5φ grain size fraction. Grain size (mm) in which 50% of the sediment is finer was also calculated for sites at Raine Island.

Table 3. Grain texture Information for sand samples collected at Raine Island

All sediments (N = 32)	Mean	Minimum	Maximum	Std.Dev.
Grain size (phi)	0.3098	-0.5949	0.894	0.3272
Grain size (Microns)	828.2106	538.1073	1510.319	205.0557
	(coarse sand)			
Skeweness	0.7464	-1.8109	3.228	1.1845
	(positively skewed)*			
Kurtosis	8.1727	2.7900	19.664	5.2128
	(Extremely leptokurtic)			
Sorting	0.5037	0.2678	0.967	0.1541
	(Moderately well sorted)			

Although mean grain size does not significantly differ with respect to beach orientation, there is a significant difference in mean grain size across beach environments (ANOVA, Current effect: $F_{(3, 12)}=4.5885$, p=.02317), with significantly coarser sediment on the reef (Figure 2), especially in the -1φ fraction. Sediment sorting at Raine Island does not significantly differ with respect to beach orientation or environment.
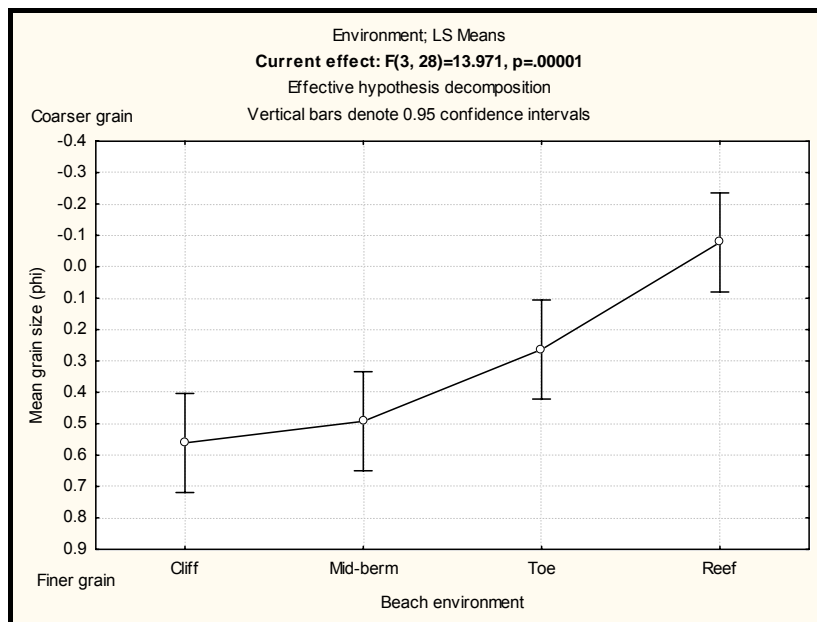

Figure 2. One way ANOVA investigating the difference in mean grain size (phi) across different beach environments at Raine Island.

Textual facies classification of Raine Island.

Using PCA and cluster analysis five facies were identified based on samples collected from Raine Island (Figure 3). Mean grain statistics are given for each cluster (facies) in Table 4.
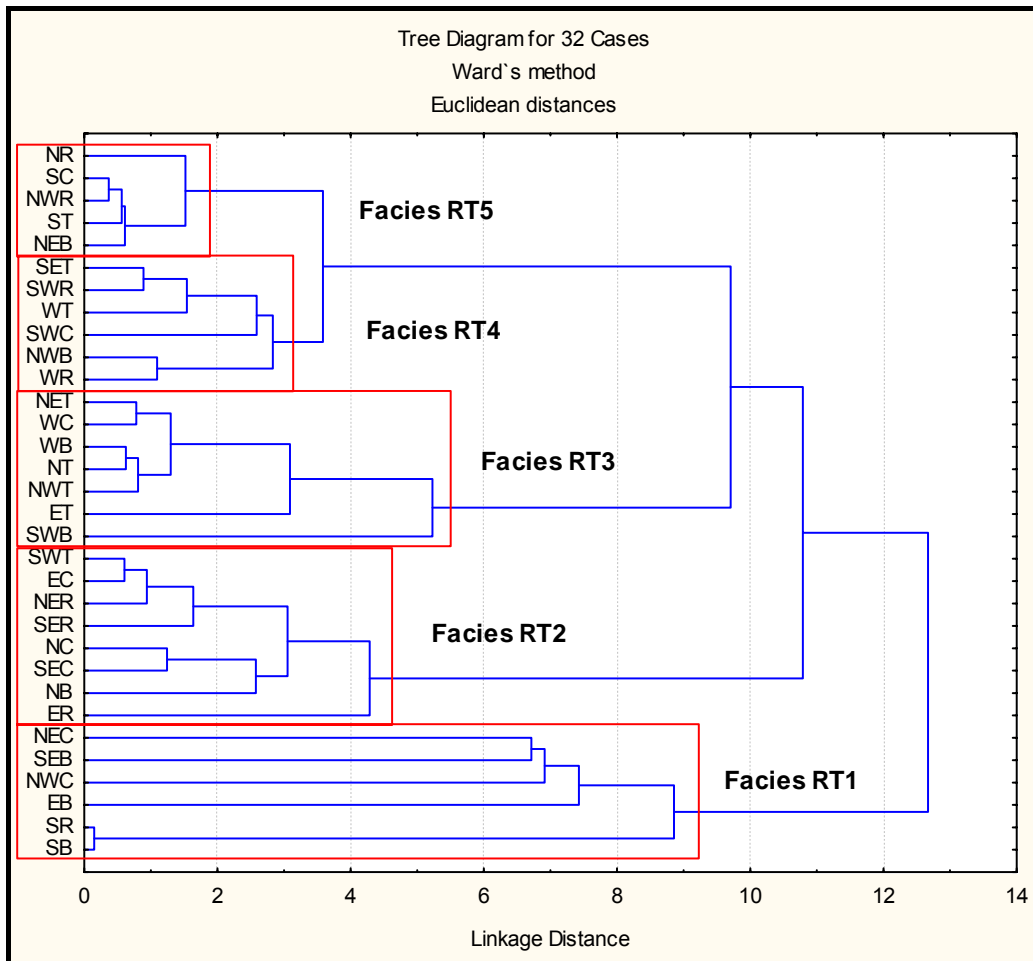

Figure 3. Hierarchical cluster analysis of all sediment samples collected from Raine Island. Sediment samples are shown on the y-axis, each indicating orientation (N,NE,E,SE,S,SW,W, and NW) followed by the beach environment (C = Cliff, B = Mid-berm, T = Toe, and R = Reef).

Cluster analysis indicates that textural facies show no direct relationship with orientation or beach environment (Figure 3). Facies RT1 and RT5 are the most dissimilar facies types while facies RT1 is the most distinctive facies type when compared to the others (Figure 3). Descriptions of each of the five facies types and their respective sediment characteristics are presented below.

Facies RT1

Facies RT1 represents 18.8% (6/32) of samples collected from Raine Island (Table 4) and the only samples to contain moderately sorted sediments and mud. A distinguishing characteristic of this facies is a higher percentage of pebbles and medium-fine sand. Sediments are positively skewed with a mean grain size of 0.34 φ (coarse sand) and are generally more poorly sorted than sediments from other facies (mean = 0.72, moderately sorted). This is due to the inclusions of pebbles and fine sand. Almost 80% of RT1 sediments are coarse to very coarse sand (Table 4). There appears to be no spatial patterns, although this facies type does not occur on the toe of the beach (Figure 3).

Table 4. Mean grain statistics of the 5 clusters (textural facies) determined from 7 extracted principle components and hierarchical cluster analysis of sediments from Raine Island.

	Facies RT1	Facies RT2	Facies RT3	Facies RT4	Facies RT5
N =	6	8	7	6	5
Grainsize (Phi)	0.34	-0.04	0.54	0.37	0.43
Grainsize (Microns)	839.69	1032.17	690.16	777.78	741.89
Sorting (SD)	0.72	0.51	0.46	0.46	0.36
Skewness	1.12	0.73	-0.03	2.06	-0.16
Kurtosis	6.92	5.88	5.46	12.88	11.49
% fine pebbles	0.40	0.00	0.28	0.00	0.25
% v. fine pebbles (granules)	10.22	6.71	0.89	0.57	0.00
% v. coarse sand	32.14	70.06	22.70	40.67	25.49
% coarse sand	47.07	21.08	69.37	55.53	72.43
% medium sand	6.41	1.14	6.59	2.11	1.68
% fine sand	3.37	1.00	0.16	1.02	0.14
% v. fine sand	0.38	0.00	0.00	0.10	0.00
% mud	0.16	0.00	0.00	0.00	0.00
% pebbles	10.62	7.44	1.17	0.57	0.25
% sand	89.00	92.56	98.83	99.32	99.75

Facies RT2

Facies RT2 represents the coarsest sediments of Raine Island. One fourth of the samples collected from Raine Island (8/32) are included in this facies (Table 4). Sediments in facies RT2 are predominantly composed of very coarse sand (70.1%) with a mean grain size of -0.04 φ. Sediments of this facies type also contain a small amount of very fine pebbles (mean = 6.7%) and are moderately well-sorted (Table 4). Again, there appears to be no distinct spatial relationship between this facies and beach orientation/environment (Figure 3).

Facies RT3

Compromising 21.9% of samples collected from Raine Island, facies RT3 is characterized by coarse sand (mean grain size 0.54 φ) and well sorted sediment (mean = 0.46, see Table 4). Sediments of this facies are characterized by a high percentage of coarse sand and relatively high percentage medium sand in comparison to other facies. There are no strong spatial patterns although this facies type is common on beach toes (Figure 3).

Facies RT4

This facies is dominated by coarse sand (55.5%) and very coarse sand (40.67%) and represents 18.75% of the samples collected at Raine Island (Table 4). Distinguishable characteristics of this facies include high values of skewness and kurtosis, compared to the other facies. As a result, grain size distributions of sediments of this facies are strongly positively skewed (2.06) and extremely leptokurtic (12.88). Although there are no direct relationships with orientation, this facies type is most common on the western half of Raine Island (Figure 3)

Facies RT5

This facies includes the smallest number of samples collected from Raine Island (Figure 3). Sediments are almost entirely coarse to very coarse sand (~98%) and well sorted (0.36). Sediments of this facies are typically the most-well sorted and grain size distributions are extremely leptokurtic ('peaky'). This facies presents the highest mean percentage of coarse sand and lowest percentage of pebbles and medium-fine sands Table 4). There are no spatial patterns of this facies in relation to either orientation or environment (Figure 3).

Compositional Analysis of Raine Island

Foraminiferans and molluscs were the most dominant constituents of sediments at Raine Island, representing means of - 34.0% and 25.1% respectively (Figure 4). Coral and coralline algae were also significant components with abundances of 17.5% and 15.1% respectively (Figure 4).

The overall compositional structure of sand found at Raine Island is similar throughout the Western, Northern and Eastern side. However, composition differs to some extent to the south with a significantly higher abundance of molluscs (approx. twice the abundance of the other 3 locations) (Figure 5). This is predominantly due to a relatively high abundance of molluscs (51.8%) found at the southern cliff area. The abundance of coralline algae is considerably lower at the Southern end of Raine Island, especially on the cliff where mean abundance is lower than 0.1%. Compositional variation is also observed on the reef area where the abundance of coral is over three times higher to the north than all other locations, while the abundance of molluscs is greater to the east and foraminifera to the south and west. Composition is relatively similar across beach zones (Figure 5) with no significant differences in component abundances found.
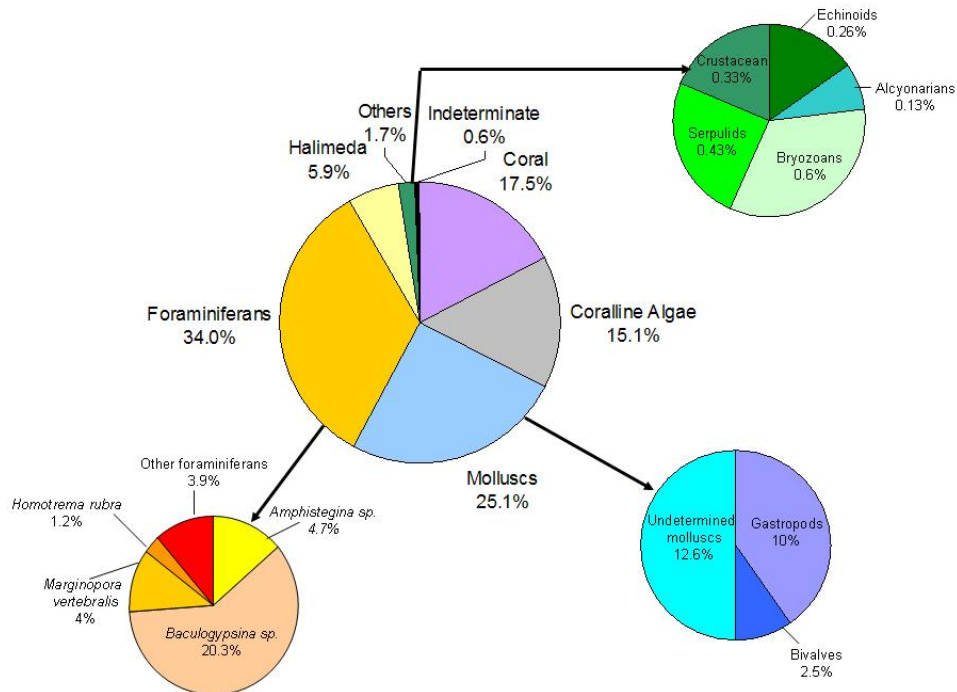

Figure 4: The skeletal composition of superficial carbonate across Raine Island.
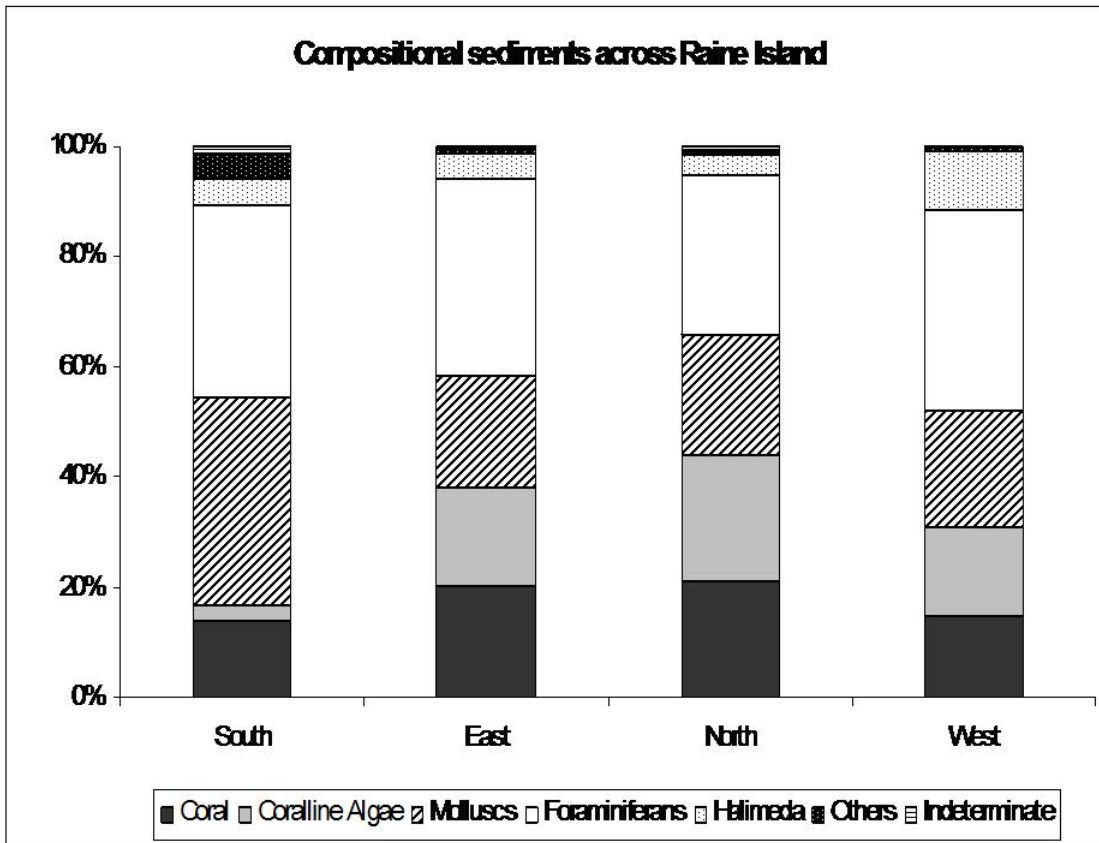
Figure 5. Mean composition of sand samples collected from Raine Island, December 2006

Foraminiferans

Foraminiferans are the most abundant sand constituent at Raine Island, representing 34.0% of the sediment. Abundance is significantly higher than at Moulter Cay and Sandbanks 7 and 8 (ANOVA, current effect: $F_{(3, 39)} = 8.5729$, p=.00017). Mean abundance varies from 18.1% (Northern reef flat) to 47.9% at (Southern reef flat). 93.8 % (15/16) of samples collected at Raine Island contain more than 25% foraminifera, of which over 80% are Baculogypsina sp. (mean weight abundance of 20.3%. No significant difference was found in the abundance of foraminifera across the beach zones (ANOVA, Current effect: $F_{(3, 11)}=.37876$, p=.77024) or at the various orientations (ANOVA, Current effect: $F_{(3, 11)}=1.0438$, p=.41152). However, it is worth noting that there appears to be considerably more foraminifera to the south and west reef areas than to the north (Figure 5).

Molluscs

Molluscs are the second most abundant element at Raine Island with varying contributions (13.4% - Northern cliff – 51.8% Southern cliff) and a mean abundance of 25.5%. Sand composition is not significantly different between the different beach zones (ANOVA, Current effect: $F_{(3, 11)}=.03864$, p=.98929). However it significantly differs between orientations (ANOVA, Current effect: $F_{(3, 11)}=4.0457$, p=.03649), with a significantly higher abundance of molluscs to the south, particularly at the cliff and sand berm.

Coral

Coral represents 17.5% of Raine Island's sediment; with abundance ranging from 9.3% at the Western reef flat to 39.6% at the Eastern toe. Mean abundance of coral does not

significantly differ across beach zones (ANOVA, Current effect: $F_{(3, 12)}=.76201$, $p=.53678$) or orientation (ANOVA, Current effect: $F_{(3, 12)}=.60327$, $p=.62527$). However, as previously noted, the abundance of coral is relatively high on the northern reef when compared to other locations (see Figure 5)

Coralline algae

Constituting 15.2% of the sediment, coralline algae, is the fourth most abundant element at Raine Island. Mean abundance was very diverse across samples, varying from 0.05% at the Southern cliff to 34.5% at the Northern cliff. Southern region at Raine Island shows a significantly lower abundance of coralline algae than the other orientations (ANOVA, Current effect: $F_{(3, 12)}=3.5778$, $p=.04686$). No significant difference was found across beach zones (ANOVA, Current effect: $F_{(3, 12)}=.60088$, $p=.62669$).

Compositional facies classification at Raine Island

Using PCA and cluster analysis explained in the methods three compositional facies were identified based on sediments collected from Raine Island (Figure 6). Mean compositions are given for each cluster (facies) in Table 5.
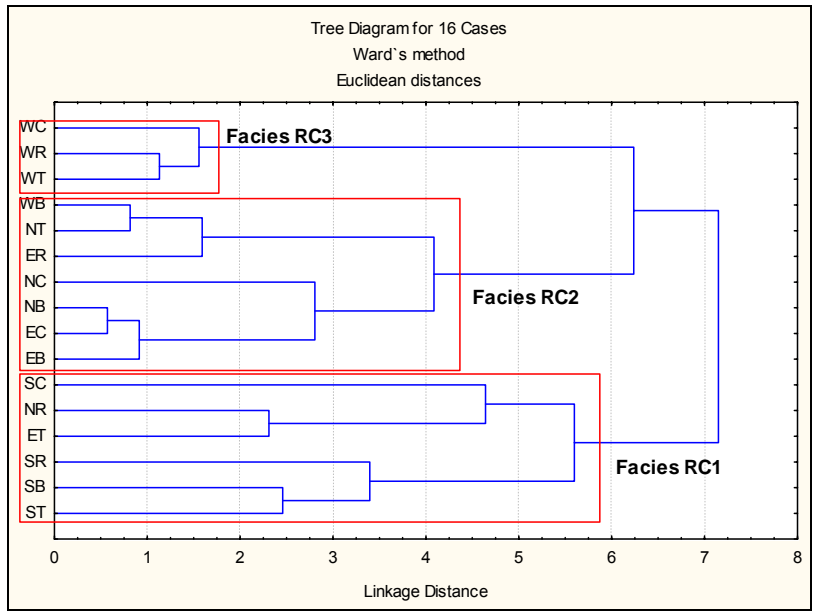

Figure 6. Hierarchical cluster analysis of all sediment samples collected from Raine Island. Sediment samples are shown on the y-axis, each indicating orientation (N,E,S, and W) followed by the beach environment (C = Cliff, B = Mid-berm, T = Toe, and R = Reef).

Cluster analysis indicates that compositional facies show some spatial relationship with orientation (Figure 6). All sediments collected from the south of Raine Island occur in the RC1, while sediments of facies RC3 are exclusive to the west (Figure 6). There is no apparent relationship between compositional facies and beach environment. Descriptions of the three compositional facies types and their respective constituent compositions are presented below.

Facies RC1

Facies RC1 is dominated by molluscs (34.69%), especially gastropods (23.60%), as well as coral (22.48%) sediments, and corresponds to 37.5% (6/16) of sediment samples collected

from Raine Island (Table 5). Other skeletal contributors are foraminiferans (30.80%) and halimeda (4.1%). The foraminifera Baculogypsina sp. has a relatively low abundance in this facies type when compared to facies RC1 and RC2 (Table 5).

Table 5. Mean composition of the 3 clusters (compositional facies) determined from 3 extracted principle components and hierarchical cluster analysis of sediments from Raine Island.

	RC1	RC2	RC3
N =	6	7	3
Coral	22.48	15.00	13.37
Coralline algae	3.15	23.77	19.04
Bivalves	2.95	1.91	2.73
Gastropods	23.60	1.97	2.43
Undetermined molluscs	8.14	16.32	12.68
Amphistegina	6.87	3.26	4.15
Baculogypsina	13.34	24.06	25.62
Marginopora	8.09	1.62	1.44
Homotrema	1.64	0.61	1.40
Other Foraminiferans	0.85	6.24	4.23
Halimeda	4.61	4.51	11.94
Echinoids	0.56	0.12	0.01
Alcyonarian spicules	0.07	0.24	0.00
Bryozoans	1.13	0.17	0.47
Serpulids	0.98	0.14	0.00
Crustaceans	0.57	0.06	0.45
Indeterminate grains	1.67	0.00	0.06
Molluscs	34.69	20.05	17.85
Foraminifera	30.80	35.85	36.84
Minor constituents	3.32	0.73	0.93

This facies type is characterized by the highest mean percentage of molluscs (mainly gastropods), coral, Marginopora vertebralis (discoidal foraminifera) and minor constituents (which includes echinoids, alcyonarian, bryozoans, serpulids and crustacean). Coralline algae is scarce in comparison to other facies (Table 5). This facies also has the highest percentage of indeterminate grains. Facies RC1 occurs throughout all beach environments but is mainly concentrated to the south.

Facies RC2

Facies RC2 is characterized by high abundances of foraminiferans (35.85%) and coralline algae (23.77%) and represents 43.75% (7/16) of sediments collected at Raine Island. Samples belonging to this facies are also characterized by a high abundance of undetermined molluscs (16.32%) and a paucity of minor constituents (0.73%), as indicated by the lowest mean percentage in comparison to other facies (Table 5). The most dominant constituent of this facies is Baculogypsina sp. (24.06%). Gastropods are scarce in this facies in comparison to the high abundance found in facies RC1 (Table 5). Facies RC2 is predominantly found to the north and east and occurs in all beach environments.

Facies RC3

Samples belonging to this facies type (18.75%, 3/16) are characterized by high abundance of foraminiferans (36.84%) and halimeda (11.94%) and low abundance of molluscs (17.85%) in comparison to the other two facies (Table 5). The lowest abundance of coral sediments occur in this facies while the most dominant constituents are foraminifera, particularly Baculogypsina sp. (25.62%). Facies RC3 exclusively occurs to the west and within all beach environments except the mid-berm.

2.3.5.2 Moulter Cay

Textual Analysis of Moulter Cay

The superficial reef sediments collected at Moulter Cay are typically coarse sand sized (mean = 0.41φ) and well sorted, but range from moderately well sorted to very well sorted (Table 6). Sediments are mostly sand-sized (97.27%), with pebble and mud sized sediments contributing only to 2.46% and 0.26% respectively. Even though mean grain size does not significantly differ across beach orientation (Current effect: $F_{(3, 8)}=.57523$, $p=.64722$), there is a significant difference in mean grain size across beach environment (ANOVA, Current effect: $F_{(2, 9)}=7.3410$, $p=.01286$), with coarser sediments on the toe (Figure 8). The toe area also presents significantly less sand from 1φ fraction (medium sand) (ANOVA, Current effect: $F_{(2, 9)}=10.163$, $p=.00491$) (Figure 7).

Table 6. Grain Information for sand samples collected at Moulter Cay

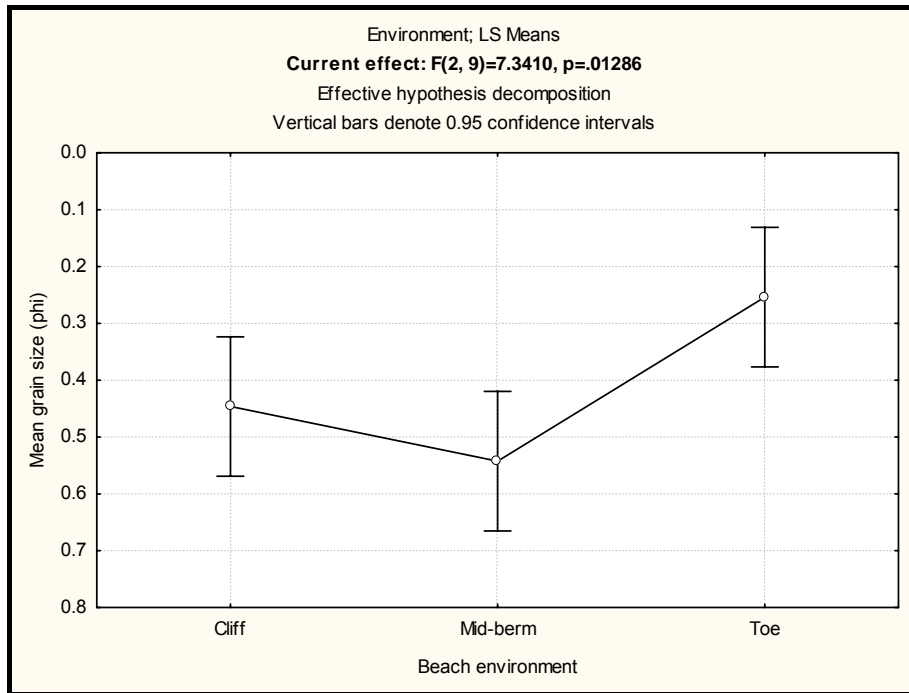| Moulter Cay(n=12)	Mean	Minimum	Maximum	Std.Dev.
Grain size (phi)	0.4142	0.0613	0.6342	0.15922
Grain size (Microns)	754.7967	644.2837	958.4004	87.64969
	(Coarse sand)			
Skeweness	-0.1908	-2.5291	2.9396	1.55443
	(negatively skewed)*			
Kurtosis	7.7355	3.3607	15.8455	4.40221
	(Extremely leptokurtic)			
Sorting	0.4054	0.2622	0.6531	0.11019
	(Well sorted)			

Figure 7. One way ANOVA investigating the difference in mean grain size (Phi) across different beach environments at Moulter Cay.

In general, the majority of sediment from Moulter Cay comprises well sorted coarse sand (mean 0.41φ), with mean variations of very coarse sand (0.06φ) to coarse sand (0.63φ) (Table 6). Grain size distributions of sediments are generally unimodal giving an overall distribution of generally unimodal with the majority of sediment belonging to the 0.5φ grain size fraction.

Textural facies classification of Moulter Cay

Using PCA and cluster analysis explained in section 3.3, two major facies types were identified based on samples collected from Moulter Cay (Figure 8). Mean grain statistics are given for each cluster (facies) in Table 7.
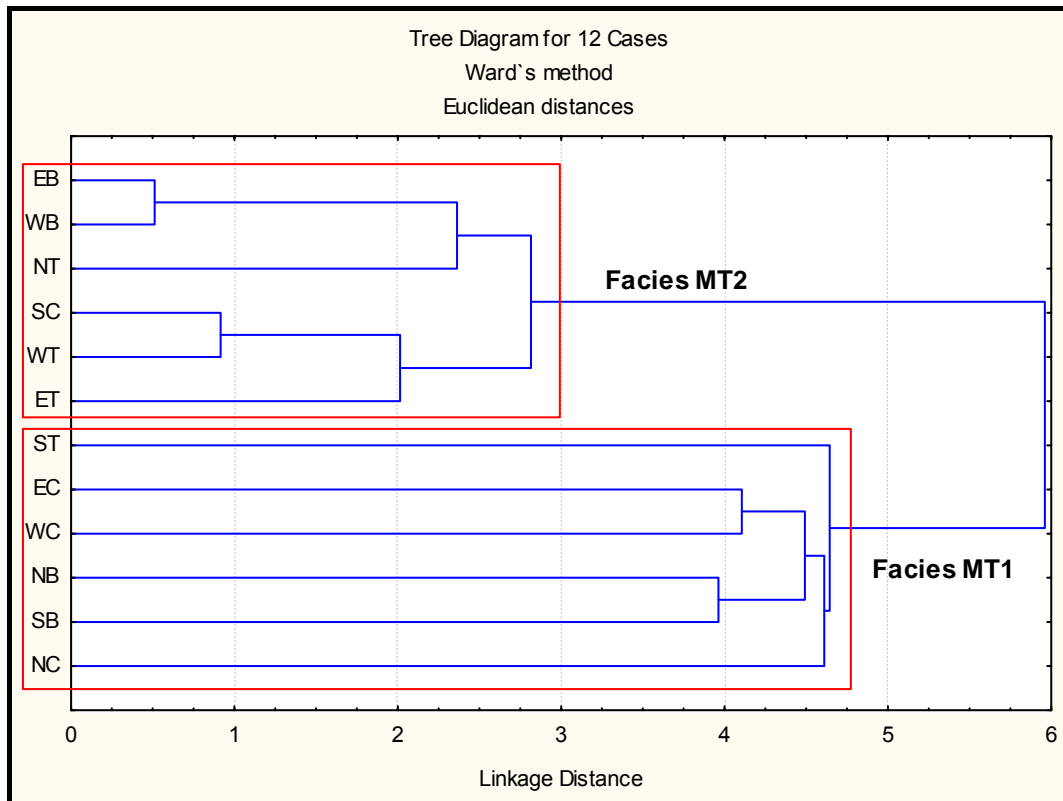
Figure 8. Hierarchical cluster analysis of all sediment samples collected from Moulter Cay. Sediment samples are shown on the y-axis, each indicating orientation (N,NE,E,SE,S,SW,W, and NW) followed by the beach environment (C = Cliff, B = Mid-berm, T = Toe, and R = Reef).

Although sediments from both facies have a mean grain size classified as coarse sand, are well sorted, and have near symmetrically skewed and extremely leptokurtic grain size distributions, they have been discriminated from each other by cluster analysis (Figure 8). Cluster analysis indicates that textural facies show no direct relationship with orientation or beach environment. However, most sediments from the cliff belong to facies MT1 while most sediments from the toe belong to MT2. Descriptions of both facies types and their respective sediment characteristics are presented below.

Table 7. Mean grain statistics of the 2 clusters (textural facies) determined from 6 extracted principle components and hierarchical cluster analysis of sediments from Moulter Cay.

	Facies MT1	Facies MT2
N =	6	6
Grain size (Phi)	0.33	0.50
Grain size (Microns)	801.46	708.13
Sorting (SD)	0.48	0.33
Skewness	-0.38	0.00
Kurtosis	8.85	6.62
% fine pebbles	0.52	0.00
% v. fine pebbles (granules)	3.34	1.05
% v. coarse sand	30.90	16.02
% coarse sand	46.82	81.11
% medium sand	4.48	1.82
% fine sand	13.02	0.00
% v. fine sand	0.40	0.00
% mud	0.52	0.00
% pebbles	3.86	1.05
% sand	95.21	98.95

Facies MT1

Samples belonging to facies MT1 comprise 50% of samples collected from Moulter Cay and are characterized as having a higher mean percentage of very coarse sand, fine sand, and pebble (31%, 13%, and 4% respectively). The majority of sediments are coarse sand-sized (mean grain size of 0.33φ) and well sorted (Table 7). Half of the sediment samples from this facies occur on the cliff area (Figure 8).

Facies MT2

The other 50% of samples collected from Moulter Cay are characterized as facies MT2, and have a mean percentage of coarse sand almost double that of facies MT1 (81% versus 47%). The mean percentage of very coarse sand is about half that of facies MT1 with a mean grain size of 0.5φ. Sediments of this facies are typically better sorted than sediments of facies MT1 and are very well sorted (0.33, see Table 11). Half of the sediment samples from this facies occur on the beach toe (Figure 8).

Compositional Analysis of Moulter Cay

The sediment collected at Moulter Cay is largely dominated by molluscs, foraminiferans, coralline algae, coral and halimeda, representing means of – 44.9%, 25%, 10.9%, 10.7% and 7.7% respectively (Figure 9).

The compositional structure throughout Moulter Cay is similar across all orientations (Beach Zones) and beach zones (Figure 10).
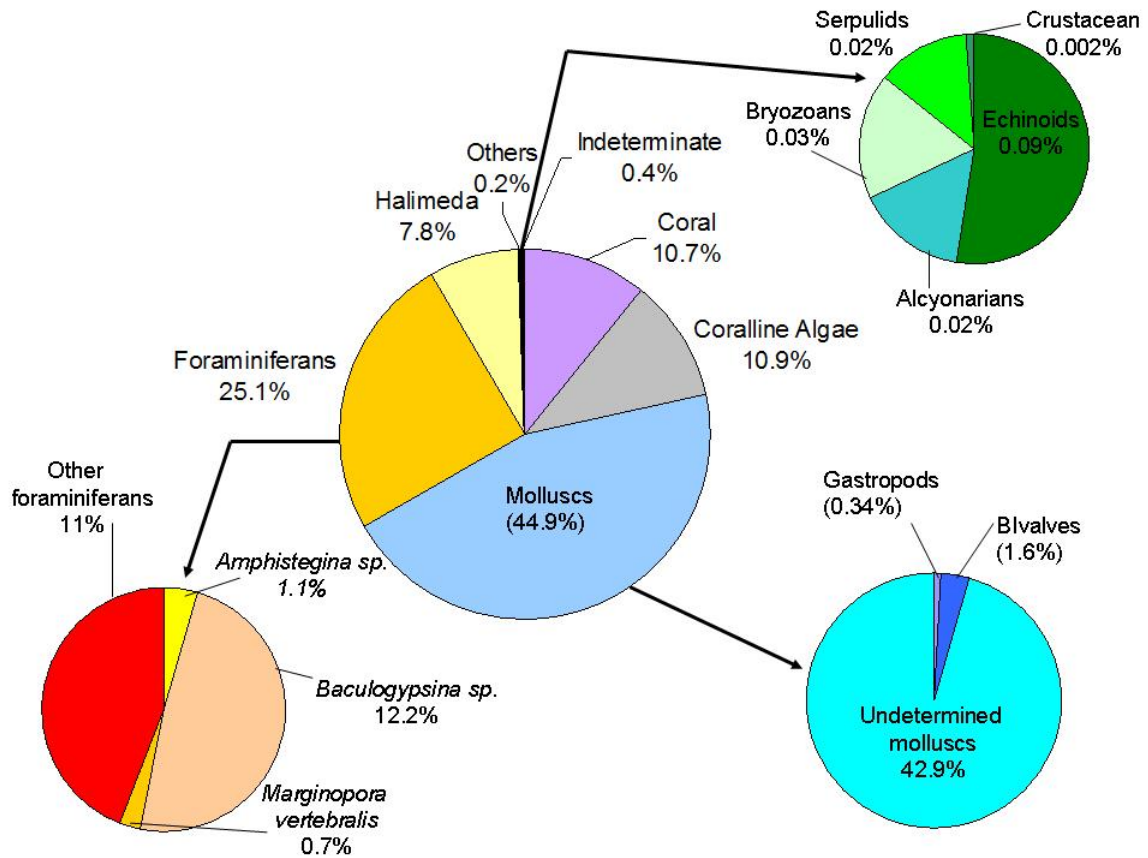

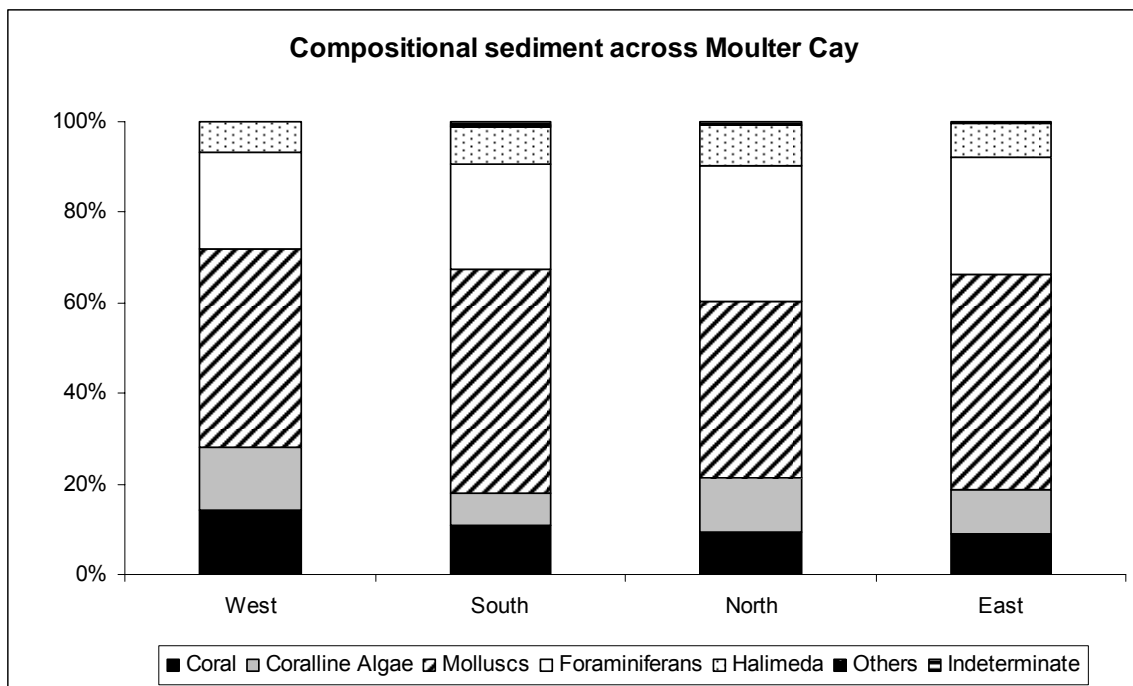**Figure 9.** The skeletal compositional of superficial carbonate across Moulter cay.

Figure 10. Mean composition of sand samples collected from Moulter Cay, December 2006

Molluscs

Mean abundance of molluscs ranged from 33.29% (North toe) to 57.66% (South midberm). Mean percentage of molluscs are not significantly different at the different beach zones (ANOVA, Current effect: $F_{(2, 9)}=.39965$ p=.68189) or beach orientations (ANOVA, Current effect: $F_{(3, 8)}=1.6402$, p=.25574). Mollusc species are predominantly undetermined.

Foraminiferans

Mean abundance of foraminiferans ranged from 19.3% (south toe) to 34.8% (North toe). Baculogypsina sp. (48.6%) and other Foraminiferans (44%) account for most of the foraminiferans occuring in sediments of Moulter Cay. Mean percentage of Foraminiferans is significantly lower on the Eastern side of Moulter Cay (ANOVA, Current effect: $F_{(3, 8)}=4.4773$, p=.03998). No significant difference on the mean percentage of Foraminiferans was found across different beach zones (ANOVA, Current effect: $F_{(2, 9)}=.67580$, p=.53279).

Coralline algae

Coralline algae is the third most dominant sediment constituent on Moulter cay, representing 10.9% of the sediment. Mean abundance varied from 5% at the middle berm on the southern side to 15% at the middle berm on the western side of Moulter cay. Mean abundance is significantly higher on western side and significantly lower on the southern side of Moulter Cay (ANOVA, Current effect: $F_{(3, 8)}=9.4563$, p=.00523). No significant difference was present across the beach zones (ANOVA, Current effect: $F_{(2, 9)}=.50604$, p=.61906).

Coral

Coral is the fourth most dominant constituent of sediments on Moulter Cay, with varying contributions from 7% (East cliff) to 17% (West midberm). No significant difference was found on the mean percentage of corals at the distinct beach zones (ANOVA, Current effect: $F_{(2, 9)}=.26319$, p=.77431) or the different orientations (ANOVA, Current effect: $F_{(3, 8)}=3.1267$, p=.08766).

Halimeda

Halimeda constituted 7.7% of the sediment at Moulter cay, with mean abundance varying from 4.1% (South middle berm) to 13.6% (South Toe). The abundance of halimeda is not significantly different across the beach zones (ANOVA, Current effect: $F_{(2, 9)}=1.6872$, p=.23863) or the different orientation (ANOVA, Current effect: $F_{(3, 8)}=.33292$, p=.80209).

Compositional facies classification

Using PCA and cluster analysis explained in section 3.3, two major compositional facies were identified based on sediments collected from Moulter Cay (Figure 11). Mean compositions are given for each cluster (facies) in Table 8. Even though both facies are very similar in relation to most constituents some differences are distinguishable in relation to abundances of molluscs, foraminifera, and minor constituents.
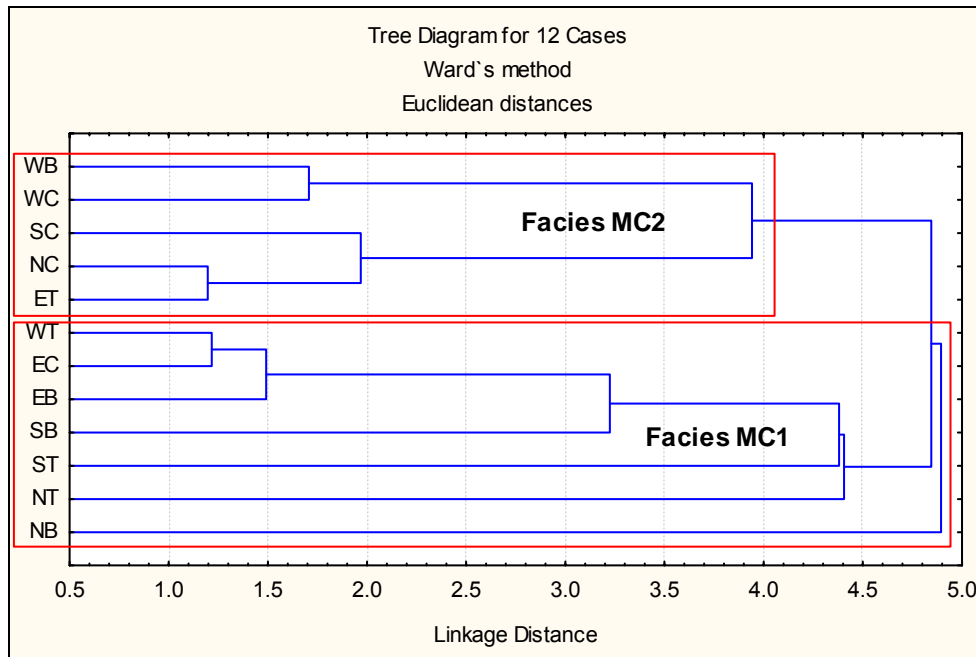
Figure 11. Hierarchical cluster analysis of all sediment samples collected from Moulter Cay. Sediment samples are shown on the y-axis, each indicating orientation (N,E,S, and W) followed by the beach environment (C = Cliff, B = Mid-berm, and T = Toe).

Table 8. Mean composition of the 2 clusters (compositional facies) determined from 2 extracted principle components and hierarchical cluster analysis of sediments from Moulter Cay.

	Cluster 1	Cluster 2
N = 12	7	5
Descriptor		
Coral	9.50881	12.43107
Coralline algae	10.10161	12.00414
Bivalves	0.17132	0.58744
Gastropods	1.85043	1.37866
Undetermined molluscs	44.37834	40.62012
Amphistegina	0.86899	1.49801
Baculogypsina	12.67030	11.49284
Marginopora	0.47689	1.01343
Homotrema	0.01829	0.00000
Other Foraminiferans	11.78168	9.99900
Halimeda	7.16723	8.56909
Echinoids	0.16142	0.00000
Alcyonarian spicules	0.04167	0.00861
Bryozoans	0.05491	0.00000
Serpulids	0.04005	0.00000
Crustaceans	0.00386	0.00000
Indeterminate grains	0.49378	0.34328
Molluscs	46.40009	42.58623
Foraminifera	25.81615	24.00328
Minor constituents	0.30192	0.00861

Cluster analysis indicates that compositional facies are very similar to each other and show little direct spatial relationship with beach orientation or environment (Figure 11). Descriptions of the two compositional facies types and their respective constituent compositions are presented below.

Facies MC1

Facies MC1 is dominated by molluscs (46.40%), especially undetermined molluscs (44.37%), as well as foraminiferal (25.82%) sediments, and these correspond to 58.33% (7/12) of sediment samples collected from Moulter Cay (Table 8). This facies type is also characterized by the highest mean percentage of minor constituents (0.30%) including echinoids, alcyonarian, bryozoans, serpulids and crustacean. Abundances of coral and coralline algae are slightly lower in sediments of this facies compared to facies MC2 (Table 8). Facies MC1 occurs in most mid-berm and beach toe environments and at all beach orientations (Figure 11).

Facies MC2

Facies MC2 is also characterized by high abundances of molluscs (42.59%) and foraminiferans (24%) and represents 41.66% (5/12) of sediments collected at Moulter cay. Samples belonging to this facies are also characterized by the highest abundance of coral, coralline algae, Halimeda, and Marginopora vertebralis, and a paucity of minor constituents (Table 8).

2.3.5.3 Sandbank 7

Textual Analysis of Sandbank 7

The superficial reef sediments collected from Sandbank 7 are almost exclusively sand-sized (99.2%) and predominantly very well sorted (Table 9). Mud-sized sediments are absent.

Overall, the majority of sediment from Sandbank 7 is very well sorted coarse sand (mean 0.33φ), with mean variations of very coarse sand (-0.11 φ) to coarse sand (0.67φ) (Table 9). Grain size distributions of sediments are unimodal giving an overall unimodal distribution with the majority of sediment belonging to the 0.25φ grain size fraction.

Although mean grain size does not significantly differ with respect to beach orientation (ANOVA, Current effect: $F_{(3, 4)}=1.6856$, $p=.30640$) and beach environment (ANOVA, Current effect: $F_{(1, 6)}=4.1160$, $p=.08881$), there is a significant difference in sediments from the 0.75φ, 1φ and 1.25φ fractions, with the berm presenting significantly more sediment from this fractions than other beach environment (ANOVA 0.75φ, Current effect: $F_{(1, 6)}=6.4321$, $p=.04431$; ANOVA 1φ, Current effect: $F_{(1, 6)}=7.4735$, $p=.03402$; ANOVA 1.25φ, Current effect: $F_{(1, 6)}=9.7867$, $p=.02037$).

Table 9. Grain information for Sandbank 7

Sandbank 7 (n=8)	Mean	Minimum	Maximum	Std.Dev.
Grain size (phi)	0.3335	-0.1122	0.676	0.2616
Grain size (Microns)	805.4232	625.7426	1080.906	151.8485
	(Coarse sand)			
Skeweness	0.3976	-1.6434	1.454	0.9588
	(positively skewed -strongly fine skewed)*			
Kurtosis	6.3414	3.9013	12.277	2.7441
	(Extremely leptokurtic)			
Sorting	0.3271	0.2454	0.433	0.0667
	(Very well sorted)			

Textual facies classification

Using PCA and cluster analysis explained in section 3.3, three major facies types were identified based on samples collected from Sandbank 7 (Figure 12). Mean grain statistics are given for each cluster (facies) in Table 10.
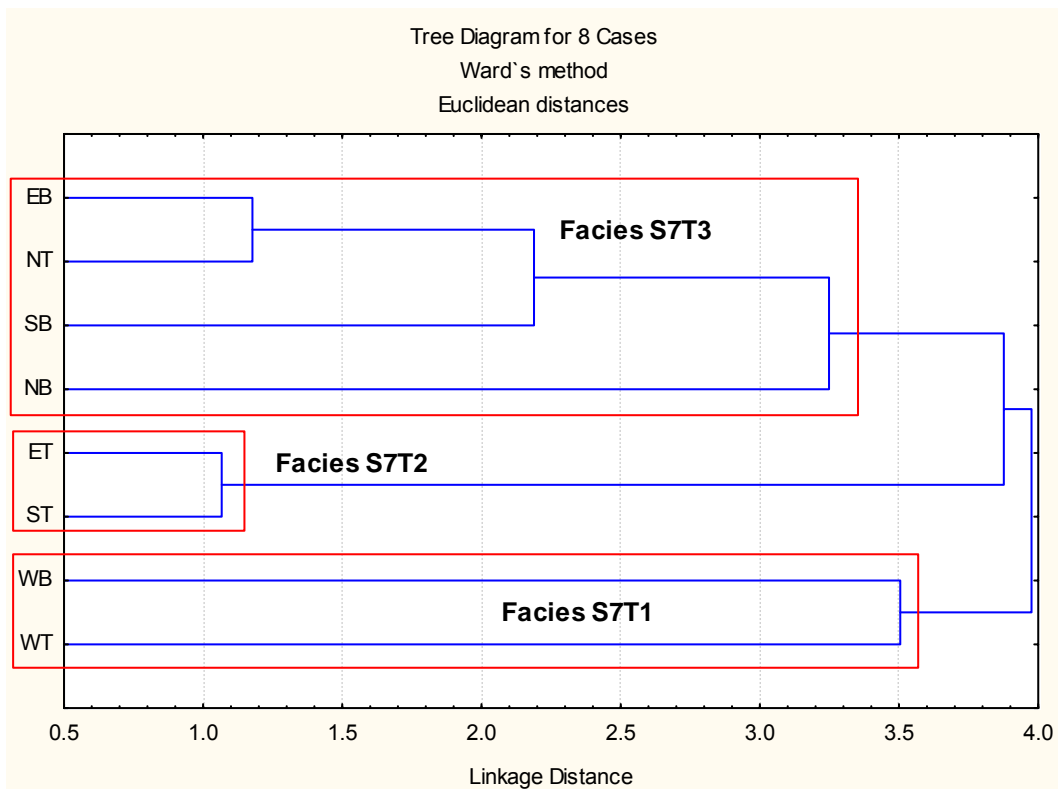

Figure 12. Hierarchical cluster analysis of all sediment samples collected from Sandbank 7. Sediment samples are shown on the y-axis, each indicating orientation (N, E, S and W) followed by the beach environment (C = Cliff, B = Mid-berm, T = Toe, and R = Reef).

Cluster analysis indicates that textural facies show no direct relationship with orientation or beach environment (Figure12). Facies S7T2 is the most distinctive facies type when compared to the others (Figure 12). Descriptions of each of the three facies types and their respective sediment characteristics are presented below.

Facies S7T1

A quarter of samples collected from Sandbank 7 belong to this facies type (Table 10). Sediments classified in facies S7T1 are predominately composed of very well sorted coarse sands (mean 87.6% coarse sand, mean grain size of 0.58φ). Sediments of this facies contain no pebbles or mud and have strongly positively skewed grain size distributions (Table 10). There appears to be a distinct spatial relationship with orientation, were this facie type only occurs on the western side of Sandbank 7.

Table 10. Mean grain statistics of the 3 clusters (textural facies) determined from 4 extracted principle components and hierarchical cluster analysis of sediments from Sandbank 7.

	Cluster 1	Cluster 2	Cluster 3
N =	2	2	4
Grain size (Phi)	0.5819	-0.032	0.3920
Grain size (Microns)	669.5360	1024.032	764.0621
Sorting (SD)	0.2821	0.285	0.3706
Skewness	0.8691	1.064	-0.1712
Kurtosis	5.9795	5.646	6.8699
% fine pebbles	0.0000	0.0000	0.4032
% v. fine pebbles (granules)	0.0000	0.0000	0.0000
% v. coarse sand	10.0800	85.5045	31.5373
% coarse sand	87.6008	14.2409	66.0530
% medium sand	2.3192	0.2547	2.0065
% fine sand	0.0000	0.0000	0.0000
% v. fine sand	0.0000	0.0000	0.0000
% mud	0.0000	0.0000	0.0000
% pebbles	0.0000	0.0000	0.4032
% sand	100.0000	100.0000	99.5968
% sand			

Facies S7T2

Samples from facies S7T2 are distinguished by having very high concentrations of very coarse sand (85.5%), in relation to the other facies (Table 10). Similarly to facies S7T1, facies S7T2 also represents a quarter of samples collected from Raine Island and contains no pebbles or mud. Sediments of this facies have a mean grain size of -0.03φ, are very well sorted, and have strongly positively skewed grain size distributions (Table 10). Although there appears to be no distinct spatial relationship between this facies and beach orientation/environment, this facies represents half of the toe areas at sandbank 7.

Facies S7T3

Facies S7T3 is dominated by coarse sand (66%) and very coarse sand (31.5%) and represents half of the samples collected at sandbank 7. This facies is distinguished from the prior two, by the presence of pebbles, albeit a small quantity (0.4%). Sediments of this facies have a mean grain size of 0.39φ, are well sorted, and have near symmetrical grain size

distributions (Table 18). Even though there are no direct relationships with environment, this facies type describes most of the berm area at Sandbank 7.

Compositional Analysis of Sandbank 7

Molluscs, foraminiferans, coral, coralline algae and halimeda are the most dominant constituents of sediment at Sandbank 7, representing means of – 47.8%, 18.8%, 14.3%, 9.8% and 7.8% respectively (Figure 13).

A similar compositional structure is present at each orientation across Sandbank 7 (Figure 14). No significant difference is found between the toe and berm areas across the different orientations. The north and west toe demonstrated compositional similarity as well as the west and east berm and the north and south berm.
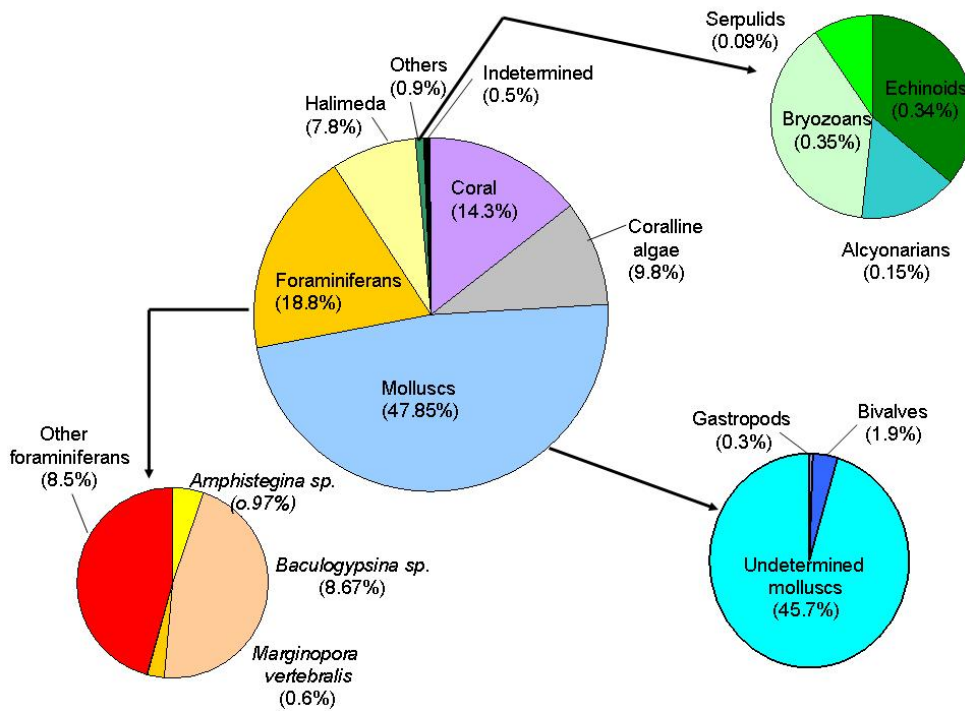

Figure 13. The skeletal compositional of superficial carbonate across Sandbank 7.

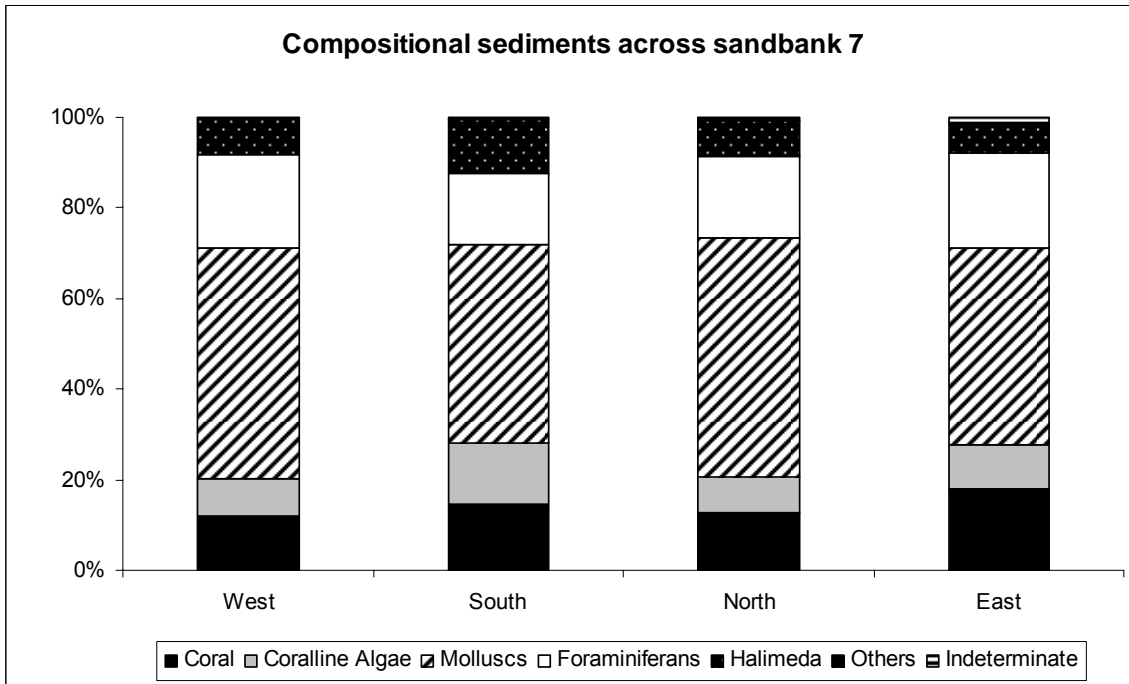**Compositional sediments across sandbank 7**

Figure 14. Mean composition of sand samples collected from Sandbank 7, December 2006

Molluscs

Molluscs are the most dominant component at Sandbank 7, compromising almost half (47.8%) of the sediment components. Mean abundance is very high across samples, with lowest abundance occurring at the eastern toe (37.7%), and highest abundance occurring at the northern toe (59.9%). The majority (94%) of molluscun sediments consisted of shell fragments that could not be identified as being gastropods or molluscs under the binocular microscope (undetermined molluscs). There were no significant difference in the abundance of molluscs across beach zones (ANOVA, Current effect: $F_{(1, 6)}=.01423$, $p=.90893$) or the orientation areas studied (ANOVA, Current effect: $F_{(3, 4)}=1.0066$, $p=.47670$.

Foraminiferans

Foraminiferans are the second most abundant component at Sandbank 7, representing 18.8% of the sediment components. The Foraminiferal sands are predomininantly composed of other foraminiferans (53.2%), Baculogypsina sp (36.25%) and Marginopora vertebralis (6.3%). Foraminiferal abundance is not significantly different across beach zones (ANOVA, Current effect: $F_{(1, 6)}=.00290$, $p=.95880$) or orientation (ANOVA, Current effect: $F_{(3, 4)}=3.5778$, $p=.12498$).

Corals

Corals represent 14.3% of sediments at Sandbank 7 and are the third most dominant component found at sandbank 7, with abundances ranging from 8% at the Northern toe to 17.4% at the Northern berm. Coral abundance does not differ significantly across the beach zones (ANOVA, Current effect: $F_{(1, 6)}=.19570$, $p=.67371$)or sandbank orientation (ANOVA, Current effect: $F_{(3, 4)}=.74370$, $p=.57944$).

Coralline Algae

Coralline algae represents 9.8% of the sediment elements at Sandbank 7, with abundance not varying greatly across the various beach environments. Lowest abundance occurs at the Northern toe, with only 5.2% of its sediment compromised of coralline algae. The highest abundance of coralline algae is found at the Northern berm, which consists of 10.2% coralline algae. No significant difference in the mean abundance of coralline algae is found across beach environments (beach zone (ANOVA, Current effect: $F(1, 6)=.02181$, $p=.88742$) or orientation (ANOVA, Current effect: $F(3, 4)=1.5244$, $p=.33774$) of coralline algae was found.

Halimeda

Halimeda is the fifth most abundant component at Sandbank 7, representing 7.8% of the sediment, with abundance varying from 4.9% (Eastern toe) to 13.7% (Southern toe). The abundance of Halimeda presents no significant difference across beach zones (ANOVA, Current effect: $F(1, 6)=.00344$, $p=.95513$) or orientation (ANOVA, Current effect: $F(3, 4)=1.7921$, $p=.28798$).

Compositional facies classification of Sandbank 7

Using PCA and cluster analysis two major compositional facies were identified based on sediments collected from Sandbank 7 (Figure 15). Mean compositions are given for each cluster (facies) in Table 11. Even though both facies are very similar in relation to most constituents some differences are distinguishable in relation to abundances of coral, coralline algae, molluscs, and minor constituents.
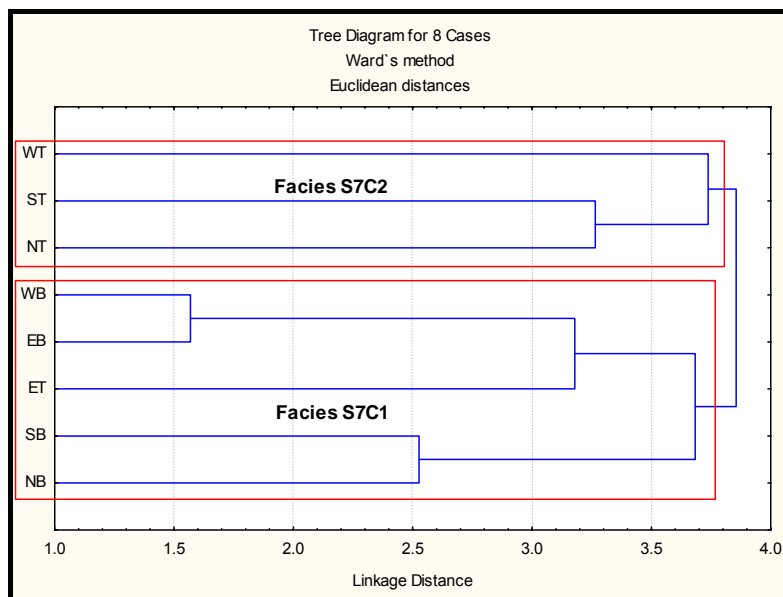

Figure 15. Hierarchical cluster analysis of all sediment samples collected from Sandbank 7. Sediment samples are shown on the y-axis, each indicating orientation (N,E,S, andW) followed by the beach environment (B = Mid-berm, and T = Toe).

Cluster analysis indicates that compositional facies are very similar to each other and show little direct spatial relationship with beach orientation (Figure 15). However, all mid-berm sediments belong to facies S7C1, and most beach toe sediments belong to facies S7C2 (Figure 15). Descriptions of f the two compositional facies types and their respective constituent compositions are presented below.

Facies S7C1

Facies S7C1 is dominated by molluscs (46.1%), foraminiferans (19.1%) and corals (16.2 %), and includes 62.5% (5/8) of sediment samples collected from Sandbank 7. This facies type is characterized by the highest mean percentage of coral and Amphistegina sp. (Table 11). Facies S7C1 is also distinguished from facies S7C2 by a slightly lower abundance of molluscs (Table 11). This facies occurs at all beach orientations but is predominantly found on the mid-berm (Figure 15).

Facies S7C2

Facies S7C2 is also dominated by molluscs (50.8%), foraminiferans (18.4%) and corals (11.1%) and includes 37.5% of sediments collected at Sandbank 7. The main difference between this facies and facies S7C1 is the lower abundance of coral, relatively higher abundance of minor constituents and a slightly higher abundance of molluscs (Table 11). All sediments belonging to this facies occur on the mid-berm.

Table 11. Mean composition of the 2 clusters (compositional facies) determined from 2 extracted principle components and hierarchical cluster analysis of sediments from Sandbank 7.

	Cluster 1	Cluster 2
N = 8	5	3
Coral	16.24374	11.11293
Coralline algae	10.35839	8.84737
Bivalves	0.21673	0.43557
Gastropods	1.42498	2.69482
Undetermined molluscs	44.41302	47.66119
Amphistegina	1.32723	0.36891
Baculogypsina	8.17012	9.51513
Marginopora	0.58050	0.52735
Homotrema	0.07910	0.00000
Other Foraminiferans	8.90753	7.97535
Halimeda	7.28638	8.68904
Echinoids	0.04644	0.82360
Alcyonarian spicules	0.05239	0.30167
Bryozoans	0.10859	0.79108
Serpulids	0.14070	0.00000
Crustaceans	0.00000	0.00000
Indeterminate grains	0.64701	0.21958
Molluscs	46.05473	50.79158
Foraminifera	19.06447	18.38674
Minor constituents	0.34812	1.91635

2.3.5.4 Sandbank 8

Textual Analysis of Sandbank 8

The superficial reef sediments collected from Sandbank 8 are predominantly sand-sized (95.5%) and very well sorted to moderately sorted. Mud-sized sediments are absent and pebbles only represent 4.45 % of the sediment.

Overall, the majority of sediment from Sandbank 8 is well sorted coarse sand (mean 0.32φ), with mean variations of very coarse sand (-0.30 φ) to coarse sand (0.74φ) (Table 12). Grain size distributions of sediments are unimodal giving an overall unimodal distribution with the majority of sediment belonging to the 0.25φ grain size fraction.

 Even though mean grain size does not significantly differ with respect to beach orientation (ANOVA, Current effect: $F_{(3, 4)}$=.65145, p=.62248) and beach environment (ANOVA, Current effect: $F_{(1, 6)}$=2.3428, p=.17674), there is a significant difference in the -0.25φ fraction and fine sand across beach orientation. There are significantly more   -0.25φ fractions (very coarse sand) at eastern Raine Island than other beach orientations, specially the western side (ANOVA, Current effect: $F_{(3, 4)}$=10.439, p=.02312). Fine sand is also significantly different across beach orientations, with the northern side having significantly more fine sand than other orientations (ANOVA, Current effect: $F_{(3, 4)}$=22.066, p=.00597).

Table 12. Grain information for Sandbank 8

Sandbank 8 (n=8)	Mean	Minimum	Maximum	Std.Dev.
Grain size (phi)	0.3269	-0.3093	0.740	0.3393
Grain size (Microns)	817.5220	598.9068	1239.069	204.5859
	(Coarse sand)			
Skeweness	0.5731	-1.2544	1.867	1.0367
	(positively skewed- strongly coarse skewed)*			
Kurtosis	6.3373	4.0279	12.139	2.5064
	(Extremely leptokurtic)			
Sorting	0.4700	0.2862	0.823	0.1653
	(Well sorted)			

Textural facies classification of Sandbank 8

Using PCA and cluster analysis two major facies types were identified based on samples collected from Sandbank 8 (Figure 16). Mean grain statistics are given for each cluster (facies) in Table 13.
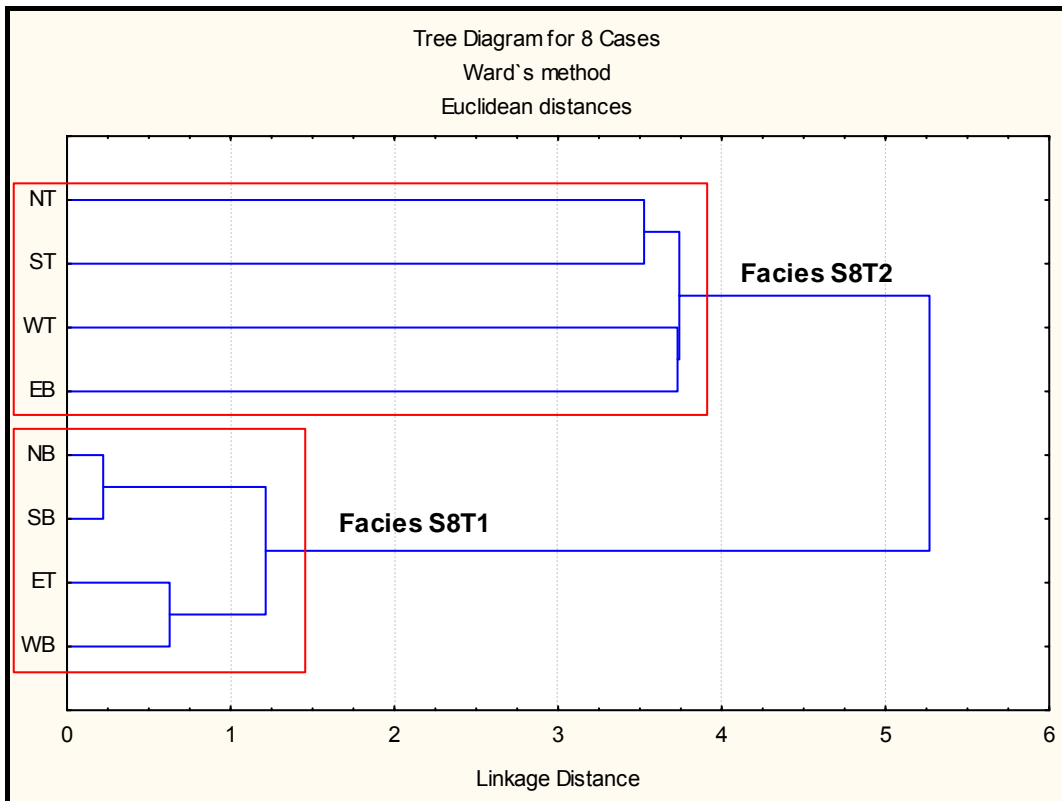
Figure 16. Hierarchical cluster analysis of all sediment samples collected from Sandbank 8. Sediment samples are shown on the y-axis, each indicating orientation (N,E,S, an W) followed by the beach environment (C = Cliff, B = Mid-berm, T = Toe, and R = Reef).

Table 13. Mean grain statistics of the 2 clusters (textural facies) determined from 4 extracted principle components and hierarchical cluster analysis of sediments from Sandbank 8.

	Cluster 1	Cluster 2
N = 8	4	4
Grain size (Phi)	0.3311	0.3227
Grain size (Microns)	798.3993	836.6447
Sorting (SD)	0.3609	0.5791
Skewness	0.7128	0.4333
Kurtosis	5.3873	7.2873
% fine pebbles	0.0000	0.2081
% v. fine pebbles (granules)	0.6697	7.9940
% v. coarse sand	39.5529	35.5300
% coarse sand	57.7981	48.7337
% medium sand	1.9504	5.6137
% fine sand	0.0288	1.9205
% v. fine sand	0.0000	0.0000
% mud	0.0000	0.0000
% pebbles	0.6697	8.2021
% sand	99.3303	91.7979

Facies S8T2

The other half of samples collected from sandbank 8, are mostly comprised of coarse sand (48.7%) and very coarse sand (35.5%). The main difference between this facies and facies S8T1 is the higher abundance of pebbles (~8%), particularly very fine pebbles. Sediments of this facies also contain a higher percentage of medium-fine sand than sediments of facies S8T1 and are generally more poorly sorted (Table 13). Mean grain size is 0.32φ, and sediments typically have moderately well sorted, strongly positively skewed grain size distributions (Table 13). Again, there appears to be no distinct spatial relationship between this facies and beach orientation/environment; however this facies type is most common on the beach toes (Figure 16).

Compositional Analysis of Sandbank 8

The most dominant skeletal constituents of sediments at Sandbank 8 are molluscs (29.2%), foraminiferans (23%), corals (20.6%), halimeda (12.4%) and coralline algae (11.2%); see Figure 35.

The overall compositional sediment across Sandbank 8 is mostly similar, except for the eastern side; where it presents a significant lower mean abundance of molluscs and a significantly higher abundance of Halimeda than other orientations (Figure 17). Compositional similarity is observed across the toe and berm area across all orientations.
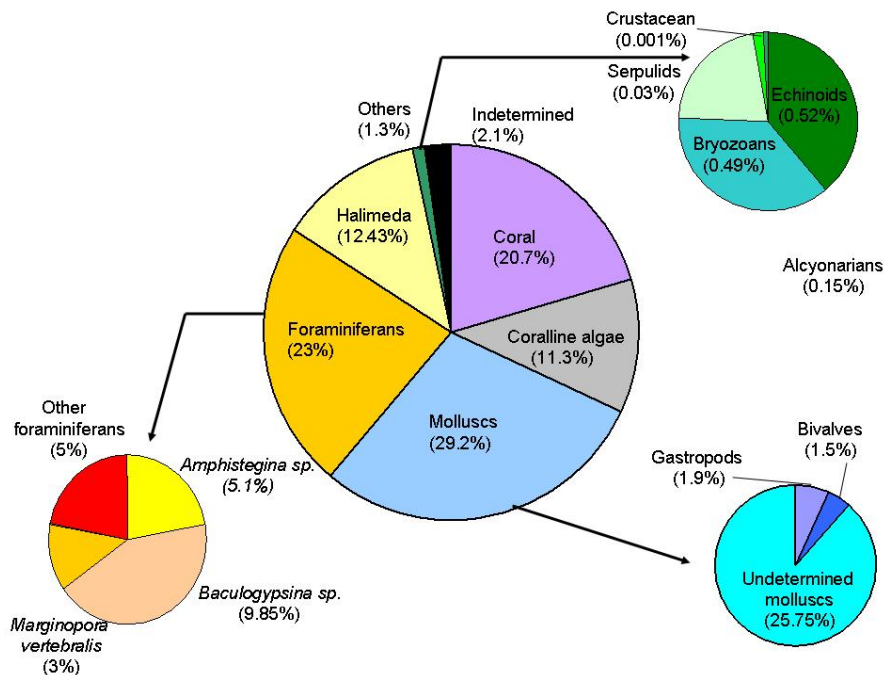

Figure 17. The skeletal compositional of superficial carbonate across Sandbank 8.

Cluster analysis indicates that textural facies show no direct relationship with orientation or beach environment on Sandbank 8 (Figure 18). Two facies were identified for samples collected from Sandbank 8. Although sediments of both facies have a mean grain size classified as coarse sand, have strongly positively skewed and extremely leptokurtic grain size distributions, cluster analysis discriminates the two facies types from each other (Figure

18). Descriptions of the two facies types and their respective sediment characteristics are presented below.

Facies S8T1

Fifty percent of sediments at Sandbank 8 belong to facies S8T1 and they are composed mainly of coarse sand (57.8%) and very coarse sand (39.5%). Facies S8T1 has well sorted sediments and a higher mean percentage of coarse sand than facies S8T2 (Table 13). Samples belonging to this facies are also distinguishable from facies S8T2 by having a lower percentage of pebbles. Mean grain size is 0.33φ, and sediments typically have well sorted, strongly positively skewed grain size distributions (Table 13). There are no strong spatial patterns although this facies type is most common on beach berm.

Molluscs

Molluscs are the most dominant constituent at Sandbank 8, representing 29.2% of the of the carbonate sediment components. Mean abundance of mollusc debris varies from 13.4% at the Eastern berm to 44.4% at the Northern berm. This difference in abundance is significantly different between different orientations (ANOVA, Current effect: $F_{(3, 4)}=11.437$, $p=.01971$), with Eastern Sandbank 8 presenting a significantly lower mean abundance of molluscs than other orientations. No significant difference in mollusc abundance was found across beach zones (ANOVA, Current effect: $F_{(1, 6)}=.42448$, $p=.53885$).
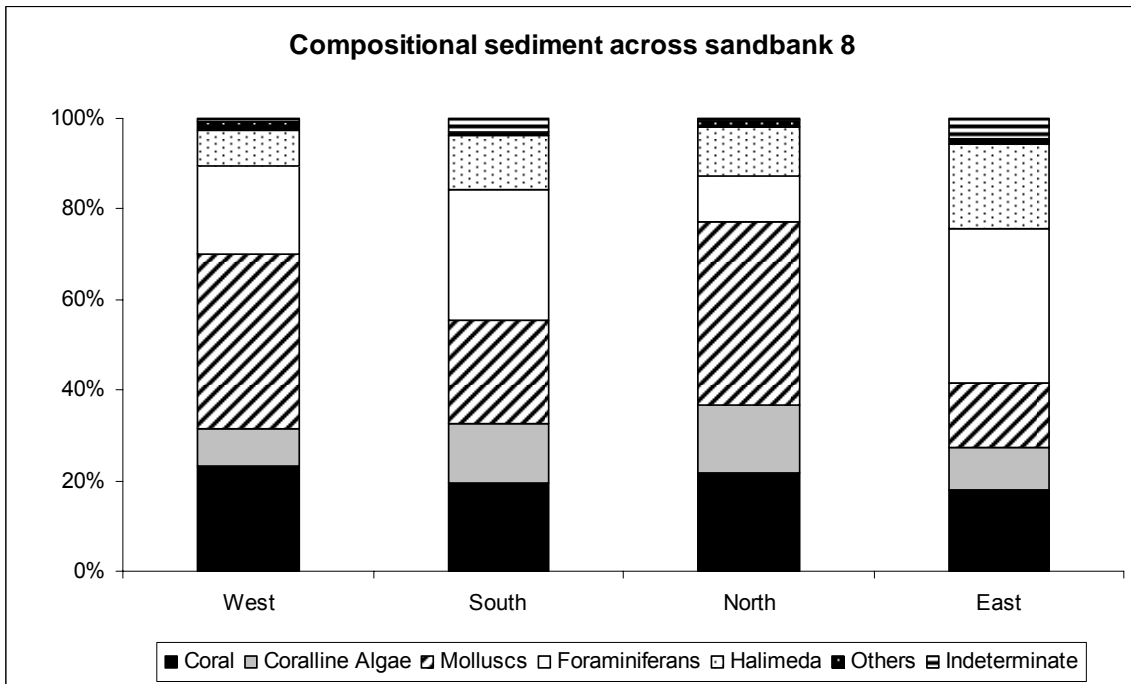

Figure 18. Mean composition of sand samples collected from Sandbank 8, December 2006

Foraminiferans

Foraminifera represent the second most abundant sediment constituent at Sandbank 8, representing 23% of all components. Baculogypsina sp. and Amphistegina sp. are the most abundant contributors to the foraminiferal sediment, making up 42.78% and 22.11% respectively. Foraminiferans abundance does not differ across its distribution (beach zones (ANOVA, Current effect: $F_{(1, 6)}=.02053$, $p=.89076$) or orientation (ANOVA, Current effect: $F_{(3, 4)}=3.6205$, $p=.12295$) .

Corals

Representing 20.6% of the constituents that make up sediments at Sandbank 8, corals are the third most dominant component found at sandbank 8; with abundances ranging from 11.5% at the Southern toe to 27.9% at the Southern berm. Coral abundance is not significantly different between beach environments (beach zones (ANOVA, Current effect: $F(1, 6)=.55515$, $p=.48437$) or orientations (ANOVA, Current effect: $F(3, 4)=.32047$, $p=.81154$) .

Halimeda

Representing 12.4% of the constituents that make up sediments at Sandbank 8, Halimeda is the fifth most dominant component found in sediments at sandbank 8; with abundances ranging from 6.9% at the Western toe to 18.7% at the Eastern berm. Halimeda abundance is significantly different (ANOVA, Current effect: $F(3, 4)=13.683$, $p=.01434$) between different orientations. The Eastern side of Sandbank 8 presents significantly higher abundances than other orientations. The abundance of Halimeda does not significantly differ between beach environments (ANOVA, Current effect: $F(1, 6)=.06730$, $p=.80398$).

Coralline Algae

Representing 11.2% of the constituents that make up sediments at Sandbank 8, coralline algae is the fourth most dominant component of sediments at Sandbank 8. The abundance of coralline algae varies greatly between environments, with 5.3% of coralline algae at the eastern berm and 21.6% at the Northern toe. However, there is no significant difference in the abundance of coralline algae between different beach environments (beach zone (Current effect: $F(1, 6)=3.8140$, $p=.09866$) or orientations (ANOVA, Current effect: $F(3, 4)=.61586$, $p=.64017$).

Compositional facies classification of Sandbank 8

Using PCA and cluster analysis two major compositional facies were identified based on sediments collected from Sandbank 8 (Figure 19). Mean compositions are given for each cluster (facies) in Table 14.
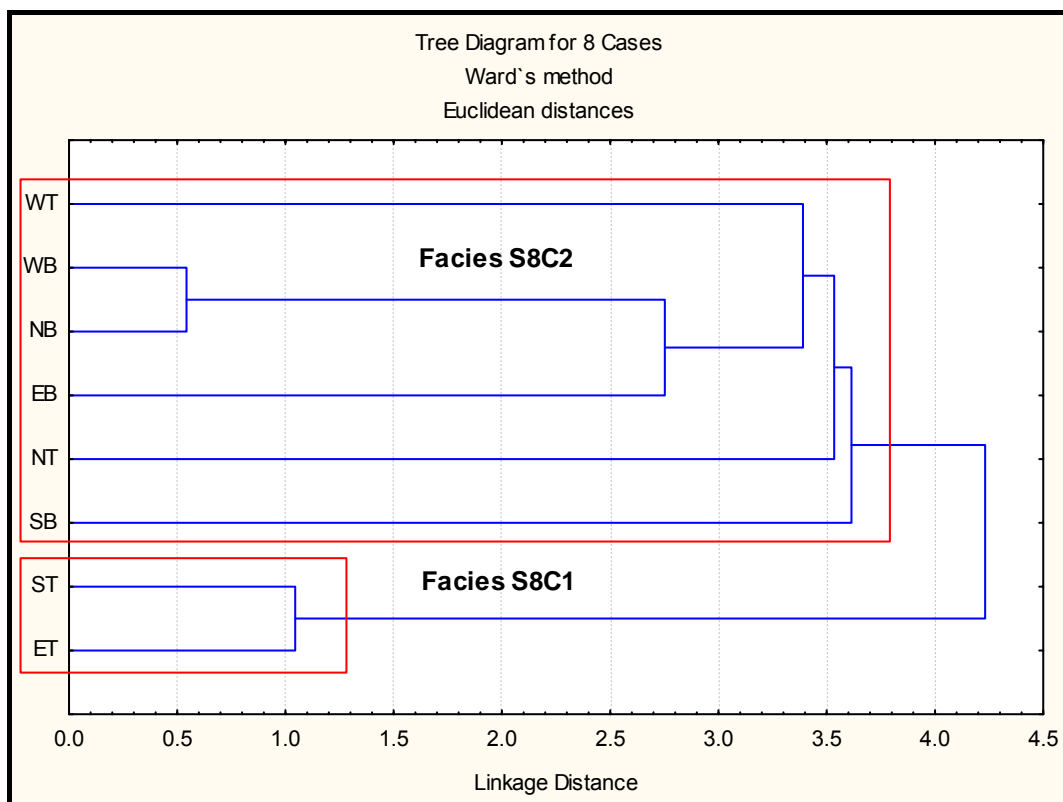
Figure 19. Hierarchical cluster analysis of all sediment samples collected from Sandbank 8. Sediment samples are shown on the y-axis, each indicating orientation (N,E,S, and W) followed by the beach environment (B = Mid-berm, and T = Toe).

Cluster analysis indicates that compositional facies at Sandbank 8 show little direct spatial relationship with beach orientation (Figure 19). However, facies S8C1 consists of sediments only from the beach toe and facies S8C2 consists of sediments only from the mid-berm (Figure19). The two facies types are relatively dissimilar. Descriptions of the two compositional facies types and their respective constituent compositions are presented below.

Facies S8C1

Samples belonging to facies S8C2 (75%) are dominated by foraminiferans (28.76%), corals (20%) and halimeda (17.9%), and includes 25% (2/8) of sediment samples collected from Sandbank 8. This facies is distinguished by having the highest mean abundance of foraminiferans, especially Amphistegina sp. and marginopora sp., as well as a greater abundance of Halimeda (Table 14). Facies S8C1 shows no relationship with beach orientation. However, both samples of this facies occurred on the beach toe (Figure 19).

Table 14. Mean composition of the 2 clusters (compositional facies) determined from 2 extracted principle components and hierarchical cluster analysis of sediments from Sandbank 8.

	Cluster 1	Cluster 2
N = 8	2	6
Descriptor		
Coral	20.08988	22.20483
Coralline algae	12.44075	10.51576
Bivalves	6.60651	0.62313
Gastropods	1.39637	1.71035
Undetermined molluscs	6.93326	31.13393
Amphistegina	11.45366	0.98559
Baculogypsina	10.22585	10.11940
Marginopora	7.08535	1.74095
Homotrema	0.00000	0.08363
Other Foraminiferans	0.00000	6.74578
Halimeda	17.98813	11.07224
Echinoids	0.90018	0.32592
Alcyonarian spicules	0.49489	0.52665
Bryozoans	0.00000	0.38051
Serpulids	0.00000	0.03441
Crustaceans	0.03651	0.00368
Indeterminate grains	4.59364	1.10791
Molluscs	14.93614	33.46742
Foraminifera	28.76485	19.67535
Minor constituents	1.43158	1.27117

Facies S8C2

Facies S8C1 is dominated by molluscs (33.4%), particularly undetermined molluscs (31.1%), as well as corals (22%) and foraminiferans (19.6%)., and includes 75% (6/8) of sediment samples collected from Sandbank 8. This facies is discriminated from facies S8C1 predominantly by a higher abundance of molluscs, particularly undetermined molluscs (31.1% versus 6.9%), and also by a lower abundance of foraminifera (Amphistegina sp. and marginopora sp.); see Table 24. Facies S8C2 also has a lower abundance of Halimeda (Table 24). Facies S8C2 shows no relationship with beach orientation. However, sediment samples of this facies were predominantly collected from the mid-berm environment (Figure 19).

All sites

Textual Analysis

Overall, the superficial sediment across the key rookeries is similar. However, significant differences are encountered regarding sediment sorting between locations, as well as the amount of 0.25φ fraction sediments across the sites.

Sorting, (measurement of the spread of the grain size distribution), is significantly lower (better sorted) at Sandbank 7 (ANOVA, Current effect: $F_{(3, 56)}=4.0685$, p=.01100); Sandbank 7 has very well sorted sediments in comparison to the well sorted sediments of the other three sites (Figure 20).

A significant difference also occurs regarding the weight percentage of 0.25φ-sized sediments across the locations, with Raine Island presenting significantly less 0.25φ-sized sediments than the other locations, particularly Moulter Cay (ANOVA, Current effect: F(3, 56)=4.8248, p=.00467).
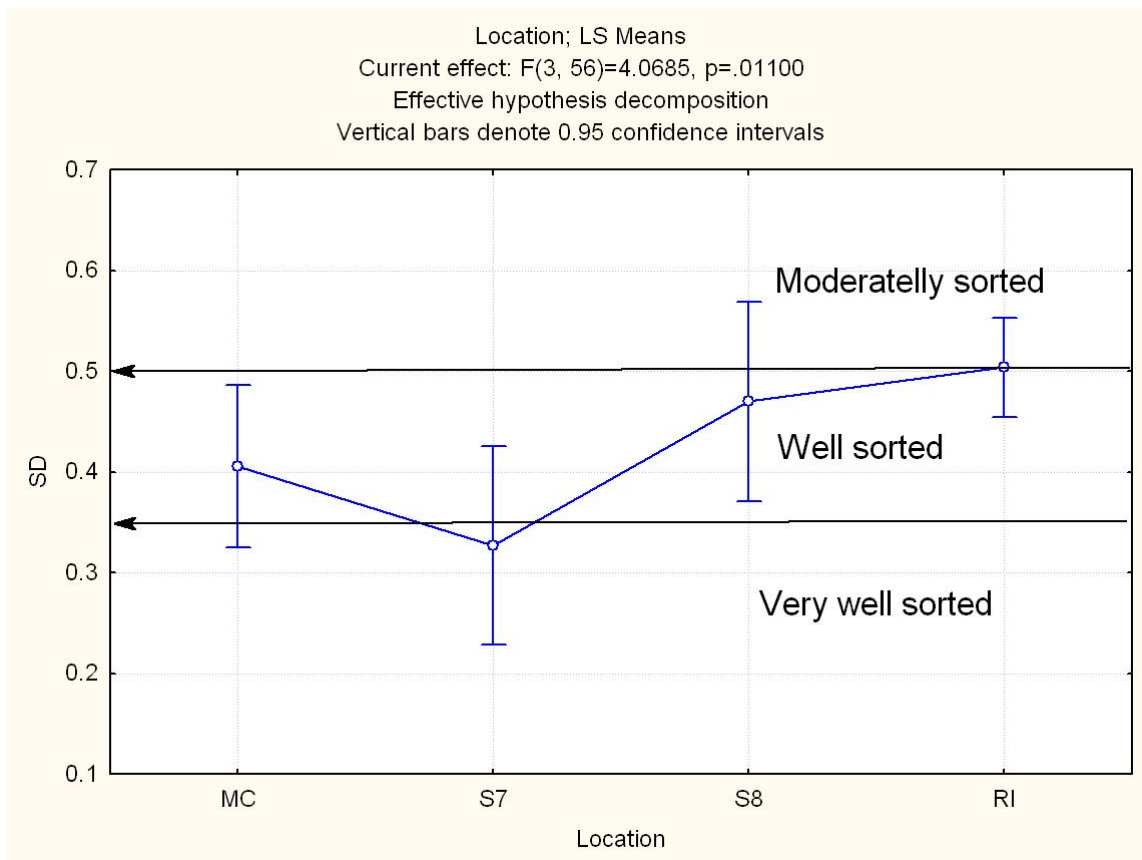

Figure 20. One way ANOVA, investigating the difference in sorting (SD = measurement of the spread of the grain size distribution) across locations.

Compositional Analysis

The composition of sediment is significantly different across the four nesting sites (Figure 12) with the only similarity being the abundance of coralline algae (ANOVA, Current effect: F (3, 40)=1.2396, p=.30808) (Figure 21). The following significant differences were found:

- Raine Island presented significantly more foraminifera than all the other nesting sites (ANOVA, Current effect: F (3, 39)=8.5729, p=.00017).
- Moulter Cay and Sandbank 7 have significantly more molluscs than Raine Island and Sandbank 8 (ANOVA, Current effect: F(3, 39)=11.427, p=.00002)
- Sandbank 8 an Raine Island have significantly more coral than Moulter Cay and Sandbank 7 (ANOVA, Cay Current effect: F (3, 40)=4.4595, p=.00856)
- Sandbank 8 has significantly more Halimeda than all the other sites (ANOVA, Current effect: F (3, 40)=6.4210, p=.00118)

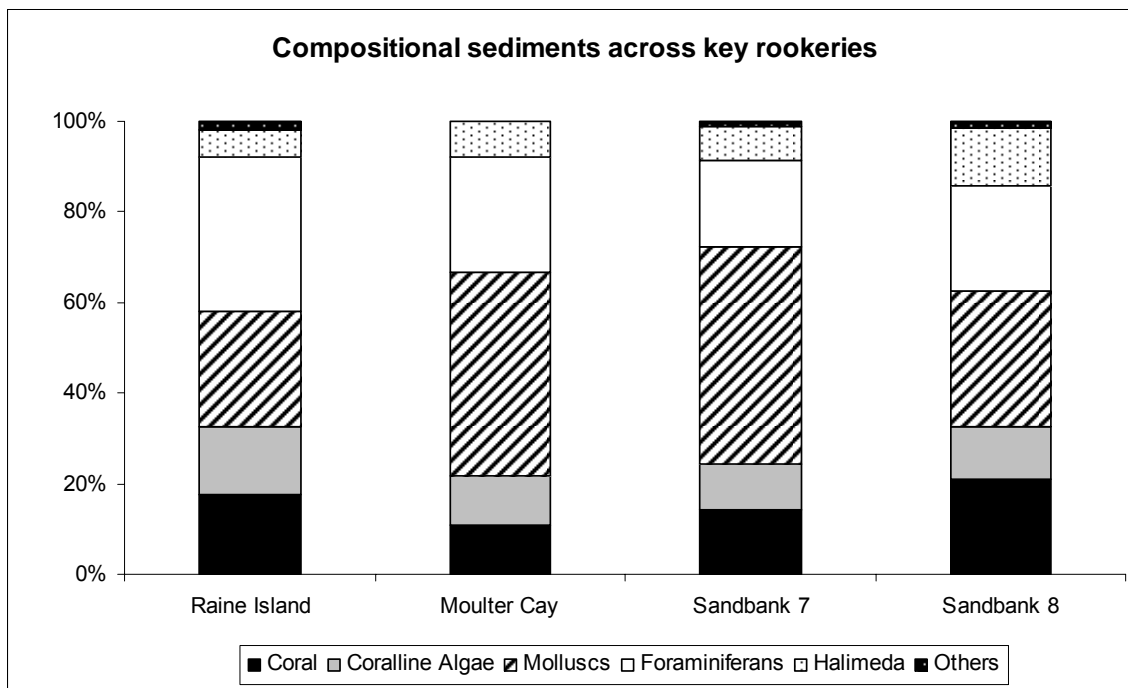**Figure 21.** Comparison of compositional analysis between Raine Island, Moulter Cay and Sandbanks 7 and 8, December 2006.

2.3.5.5 Main Findings of sand sample analysis

The textual and compositional facies identified at each rookery demonstrated some important differences and similarities on the hydrodynamic environment and sites of sedimentation across the rookeries. Moulter Cay and Sandbank 7 demonstrated to be the rookeries with most energy, and therefore more susceptible to climatic events. Contrary, Raine Island and Sandbank 8 presented characteristics of low energy islands.

Raine Island

Deposit from extreme storm events to the northern beach. The predominance and high abundance of corals on the northern reef area may reflect deposition during storm events and high energy waves. Since Dawson 2006, suggests that high currents would be necessary to transport corals greater than 4mm from their source to the beach. There is evidence to support the transport of material from the reef flat and north beach to the western beach. The high concentration of benthic foraminifera on the western beaches may represent an area of sediment supply (accretion) from i) the reef flats; ii) longshore drift. The latter is the more probable with source material coming from the presently eroding north shore and being transported around to the northwest. A lower energy system is found on the western side.
A shift in wind patterns due to climate change may have a severe effect on the erosion of the northern part of the island.

Moulter Cay

Moulter Cay has residual deposits of the most durable skeletal components. Molluscs have a high level of skeletal durability in comparison to other components (Milliman 1974; Scoffin 1992). The predominance of molluscs at Moulter Cay may reflect a residual deposit as the consistent reworking of waves breaks down most other components.

Sandbank 7

Sandbank 7 has residual deposits of the most durable skeletal components. Similarly to Moulter cay, Sandbank 7 also has a prevalence of molluscs. Intense wave energy at the southeastern beach is indicated by the high concentration of very coarse and very well sorted sediments at the south and east beaches.

Sandbank 8

Low energy at eastern beach. High abundance of Halimeda on the eastern beach indicates a low energy environment, since Halimeda is easily destroyed by mechanical abrasion and does not last through high winds and waves. There is evidence of a high energy and residual deposit on the northern and western beaches. High abundance of molluscs and corals on these regions may be explained by a residual deposit due to a high energy system.

2.4 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 represents the first quantitative assessment of the Dowar Island green turtle rookery.

Our data from suggest that in the 2006/2007 breeding season between 300 and 500 females emerged each night during December on Dowar Island, and thus it is likely that between 500 and 800 females emerged each night in December within the Mer group (Mer, Waer and Dowar Islands). Because the average number of females breeding in 2006/2007 at Raine Island was well above average (Col Limpus personal communication), we assume that the nightly counts we recorded at Dowar Island also represented an above average figure.

One of the key threats that have been identified for green turtles in the nGBR/TS 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 10% (Limpus et al. 2003, Limpus et al. 2005; Col Limpus personal communication), even in late season nesting and in nights following rainfall (QPWS unpublished data and Hamann personal observation). We recorded variable nesting success among the two of the three beaches at Dowar. At the southern beach we recorded low nesting success in December (32%) and this increased to 55% in February once regular nightly rainfall had begun and the number of females ashore each night had declined. Given the low percent of nesting success at Raine Island it is important that nesting success be calculated at other rookeries so that more accurate data on hatchling production can be determined.

Similar to most marine turtle studies we found that hatchling production varies between and within rookeries. Our data from Dowar Island indicate that nests laid out on the open sand areas typically had higher success than those laid under the trees or close to the edge of the beach (rock face). Our values for hatchling emergence from Dowar Island were similar to data collected at Bramble Cay (Limpus et al. 2001) and Raine Island (Limpus et al. 2003).

The biological data collected from green turtles nesting at Dowar Island is likely to be similar to data collected from other rookeries given that the turtles are from the same population. However, we found that the mean size of turtles nesting at Dowar Island is at the lower end of the mean sizes for turtles recorded nesting between 1976 and 2001 at Raine Island. The mean size of nesting turtles fluctuates with the number of turtles breeding each year, and has been declining steadily at Raine Island (Limpus et al. 2003) and the Coral Sea (Harvey et al. 2005). A longer-term data set from Dowar Island is required to determine if similar trends exist.

Although nesting success was low in December at Raine Island we did not record any turtles switching to Dowar Island from any other study sites. This fidelity is complementary to results from previous studies on green turtles in the Torres Strait and northern GBR (Limpus et al. 2001 and 2003).

Geomorphology

This study presents the first assessment of sand composition for green turtle rookeries in Queensland. To date only the sand composition values for samples collected from Raine Island, Moulter Cay and the two Sandbanks have been analysed. The preliminary data from these four locations reveal both within and between island differences in sand composition. It is interesting that Raine Island has a higher percentage of forams than the other islands, as forams tend to be more buoyant than other sand components. A more detailed assessment will be possible once the sand texture and facie analysis is completed.

2.5 Baseline evaluation of key threats

The nGBR/TS green turtle population is the largest green turtle population in the world. Long term data sets collected by QPWS since 1976 reveal strong fluctuations in the number of females nesting each year, and these fluctuations make trend detection difficult (Limpus et al. 2003). However, since 1996 several biological indicators have been suggested as early in warning signs that the population is in early stages of decline; for example declining size of nesting turtles. In addition, in the last 10 years the proportion of females ashore on any night that successfully lay eggs, and hatchling production has been very low and approaching zero. Several factors have been identified as likely or probable causes; gradual net sand loss from the island, changes to the beach rock profiles, flooding of nests, very dry sand that does not allow nest digging, or combinations of the above. Factors underlying these causes could be both natural and anthropogenic (as a result of island or reef crest alteration during the mining operations). Given that it is generally accepted that successful sea turtle populations require in order of 75% hatchling production to maintain recruitment it is clear that the low nesting success and poor hatchling production is not sustainable at current levels.

Whether or not similar patterns (nesting success and hatchling production) occur at the other main rookeries is less well known. While it is emerging that there are erosion problems at Bramble Cay, and data from other cays are non-existent or inconclusive Raine Island and Moulter Cay support 90% of the annual nesting so essentially what occurs on these two islands will drive the short-term future of the population. Continued monitoring of other green turtle rookeries will be necessary to develop an understanding of whether turtles are shifting from Raine Island to other rookeries.

A consequence of poor hatchling production will be reduced juvenile recruitment into the foraging areas 5 to 10 years later. Given that the poor hatchling production was first recorded in 1996 surveys in the coming years will be crucial to assess rates of recruitment. Our baseline data (small sample size) from turtles caught within the Inner Islands of Torres Strait indicate that 1-2% of turtles caught are new recruits to the foraging habitat (Hamann et al.

2005 and unpublished data). A larger sample size is required to develop a reliable estimate of this parameter.

3. Acknowledgements
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