A Synthesis of Climate Change and Coastal Science to Support Adaptation in the Communities of the Torres Strait

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Executive Summary

This report provides a synthesis of research on climate change and coastal science in the Torres Strait, and has been produced for the Australian Government's Marine and Tropical Sciences Research Facility (MTSRF). It identifies and summarises work to date on reef evolution, hydrodynamics and sedimentary environments throughout the Torres Strait. It describes the island dynamics at Boigu, Saibai, Masig, Poruma, Warraber and Iama Islands. Numerous studies relating to climatic change are reviewed and the most relevant regional predictions for climate change in the Torres Strait are presented. The potential physical and ecological impacts of these changes in the Torres Strait are also identified. Adaptation and mitigation measures are suggested and their outcomes and consequences are evaluated. The key principles from sustainable land use plans on the islands are summarised and knowledge gaps in the fields of both coastal and climatic science are identified to guide future research.

The most important factor influencing the hydrodynamics of the islands of the Torres Strait is the seasonally reversing wind regime, characterised by dominant southeasterlies for nine months of the year (March to November) and northwesterlies over the summer months (November to March). The tidal regime through the Torres Strait is complex and is also fundamental to the morphodynamics of the islands. Surge events are characterised by an elevation of mean water level caused by pressure and wind set up, often resulting from storms some distance away. Such events occur in the Torres Strait and are responsible for much of the geomorphic work performed on the island beaches. Summaries of island dynamics are described for those locations at which data are available, and the areas vulnerable to coastal erosion and inundation are identified.

Climate change is expected to result in the warming of average air and ocean temperatures, average global sea level rise, ocean acidification and regional changes to wind and precipitation patterns and extreme weather events. It was recognised that the exact nature and rates of these changes remain uncertain particularly at regional and local scales. In Torres Strait the best available estimates suggest that local air temperatures will increase by 1-4°C and sea surface temperatures by up to 3°C by the year 2070. Sea level rise of up to one metre is also projected to occur by the year 2100. Other changes in regional climatic conditions predicted include a ten percent increase in downwards radiation, between 0.8 and 13% increase in wet season rainfall, between 3.9 and 23% decrease in dry season rainfall, and a 16% increase in evapotranspiration by the year 2070. Wind speed is expected to increase by between two and five percent by 2030, accompanied by uncertain changes to wind direction trends.

Ecological impacts on the health of coral reef and seagrass communities, as well as species of concern including turtles and dugongs, in the Torres Strait are predicted to result from these climatic changes. These impacts include increased coral bleaching events, a temperature induced decline in turtle hatchling survival and an imbalance in the gender of hatchlings.

The most concerning immediate physical impacts likely to result from these climatic changes relate to inundation affecting island infrastructure, vegetation and water sources and coastal erosion threatening infrastructure and sites of cultural significance. The exact nature of these impacts will vary from island to island. In some cases, sea level rise could potentially increase the transport of sediment from reef flats to islands, causing them to grow. However, in general, these impacts will decrease the amount of viable land on islands and, unless managed well, will cause decline in the quality of life for the communities of Torres Strait. Relocation to higher ground must be planned and the potential relocation of some communities must be considered. This report identifies numerous adaptation and mitigation measures, including hard and soft engineered works, which can minimise these physical impacts and even improve island condition. These must be considered on an island by island basis to ensure they are successful and that the negative consequences are understood, minimised and acceptable to the communities.

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Acronyms and Abbreviations Used In This Report

ACE CRC .... Antarctic Climate & Ecosystems Cooperative Research Centre
BOM .... Bureau of Meteorology (Australia)
CO_2 .... Carbon dioxide
CPU .... Coastal protection unit
CRC .... Cooperative Research Centre
CSIRO .... Commonwealth Scientific and Industrial Research Organisation
ENSO .... El Niño-Southern Oscillation
EPA .... Environmental Protection Agency (Queensland) (now Department of Environment and Resource Management)
GBR .... Great Barrier Reef
GCM .... Global Climate Model
Gt .... Gross tonnage
HAT .... Highest astronomical tide
hPa .... Hectopascals
IPCC .... Intergovernmental Panel on Climate Change
JCU .... James Cook University
LAT .... Lowest astronomical tide
LIDAR .... Light detection and ranging
MSL .... Mean sea level
MSQ .... Marine Safety Queensland
ppm .... Parts per million
PNG .... Papua New Guinea
SLUP .... Sustainable land use plan
SST .... Sea surface temperature
SWH .... Significant wave height
TSRA .... Torres Strait Regional Authority
YBP .... Years before present

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We also thank the members and staff of the Torres Strait Regional Authority, particularly Toshie Kris, Walter Mackie, Wayne See Kee, Damian Miley, Vic McGrath, David Hanslow and Miya Isherwood for their support and insights, which helped us to understand the island environments and to work with the communities.

1. Introduction

The islands of the Torres Strait and their inhabitants are widely, and accurately, reported to be vulnerable to natural and human induced changes to their coastal environment, particularly as a result of climate change. The Torres Strait is a diverse, environmentally complex and important area but is still relatively poorly studied (Harris *et al.* 2008). The area is understood to be particularly vulnerable to the effects of global climate changes, particularly sea level rise, atmospheric and ocean temperature rise, increases in ocean acidity and changes to the regional climate regimes. In addition, Torres Strait communities face challenges from increasing population pressure, increased pollution, introduced pests and increasing resource exploitation (Harris *et al.* 2008). In these island environments, climatic and coastal processes are closely linked. Thus, to successfully manage the islands and formulate adaptation plans for the changing future, climatic and coastal science must be approached together. The integration of both scientific and community perspectives is of the utmost importance.

To successfully plan for the future it is imperative that communities know as much as possible about climate change and the impacts it is likely to have on the islands. Adaptation measures put in place to respond to the challenges must be owned by the communities and the consequences of actions must also be understood. This report provides a brief and accessible synthesis of coastal science that has been undertaken in the Torres Strait to date, summarising the climatic conditions, evolutionary history, hydrodynamics, sedimentary environment and island dynamics. It also summarises climate change science applied to the region and presents the best available projections. This report aims to help communities make informed decisions regarding the future of their Islands.

1.1 The Torres Strait

Torres Strait is the body of water between the northern tip of Australia and the southern border of Papua New Guinea (PNG) (Figure 1.1).The Strait is mostly shallow (in most places between 5-25 m deep) and lies between two major ocean basins, the Arafura Sea/Gulf of Carpentaria to the west and the Coral Sea to the east (Wolanski *et al.* 1988). It covers an area of approximately 48,000 km^2. It is also a major shipping route and an important fishery.

Governance of the area is complex with the Commonwealth Government managing most of the marine area, and the Queensland State Government managing the islands. The region is covered by the Australia-Papua New Guinea Torres Strait Treaty (SLUP, 2010).

The bathymetry of the Torres Strait is complex, and outside major shipping channels bathymetric data is sparse (Hemer *et al.* 2004). The region is diverse and has a multitude of ecological habitats, including mangroves, seagrass beds, approximately 750 coral reefs and more than 270 islands (Souter, 2007). The islands range in size and type from small vegetated and unvegetated sand cays to volcanic islands and larger rocky continental islands (Harris *et al.* 2008). Seventeen of the islands are permanently inhabited and the region has a population of approximately 8,500 (SLUP, 2010).

The islands in the Torres Strait are frequently classified for administrative purposes into five island clusters: the eastern islands, central islands, top western islands, western islands and inner islands. Each island and island cluster is unique in cultural identity, location, physical form, island type, formation processes and the geomorphic processes at work there. Given these differences the impacts of climate change will vary from island to island and management and adaptation options will need to be tailored accordingly. Only some of the islands are inhabited. The many uninhabited islands are also important to the communities and are used for a variety of purposes. In addition, the many coral reefs of the region are important because of their resources which are used for food and for commercial purposes.

Four types of island are found in the Torres Strait: reef (cay) islands, continental (high) islands, low lying muddy islands and volcanic islands (Table 1.1). Reef islands, including the communities of Masig, Poruma and Warraber in the central island group, are low lying coral cays formed on reef flats. Continental islands, formed by granite mountains, include the communities of St. Pauls and Kubin on Moa, Badu, Mabuiag, Dauan in the Western island group and Iama in the Central island group and Thursday, Ngurupai, Muralug and Hammond Islands from the Inner island group. Islands in the eastern group are mainly volcanic and include the communities of Mer, Erub and Ugar. The low lying Top Western islands of Boigu and Saibai were formed mainly from muddy alluvial sediments derived from rivers in PNG. They have significant mangrove habitat (SLUP, 2009). Two mainland communities on Cape York Peninsula, Bamaga and Seisia, primarily populated by people who identify as Torres Strait Islanders, are also part of the Torres Strait for many administrative purposes.

Table 1.1. Traditional and English names of inhabited islands within the Torres Strait, showing the island group and type to which it belongs.

Island Group	Traditional Name	Western/ English Name	Island Type
Top Western Islands	Boigu		Low lying muddy island
	Dauan		Continental island
	Saibai		Low lying muddy island
Western Islands	Badu		Continental island
	Mabuiag		Continental island
	Moa (Kubin and St. Pauls communities)		Continental island
Central Islands	Iama	Yam	Continental island
	Masig	Yorke	Reef island
	Poruma	Coconut	Reef island
	Warraber	Sue	Reef island
Eastern Islands	Mer	Murray	Volcanic island
	Ugar	Stephan	Volcanic island
	Erub	Darnley	Volcanic island
Inner Islands	Kirriri	Hammond	Continental island
	Muralug	Prince of Wales	Continental island
	Ngurupai	Horn	Continental island
	Waiben	Thursday	Continental island

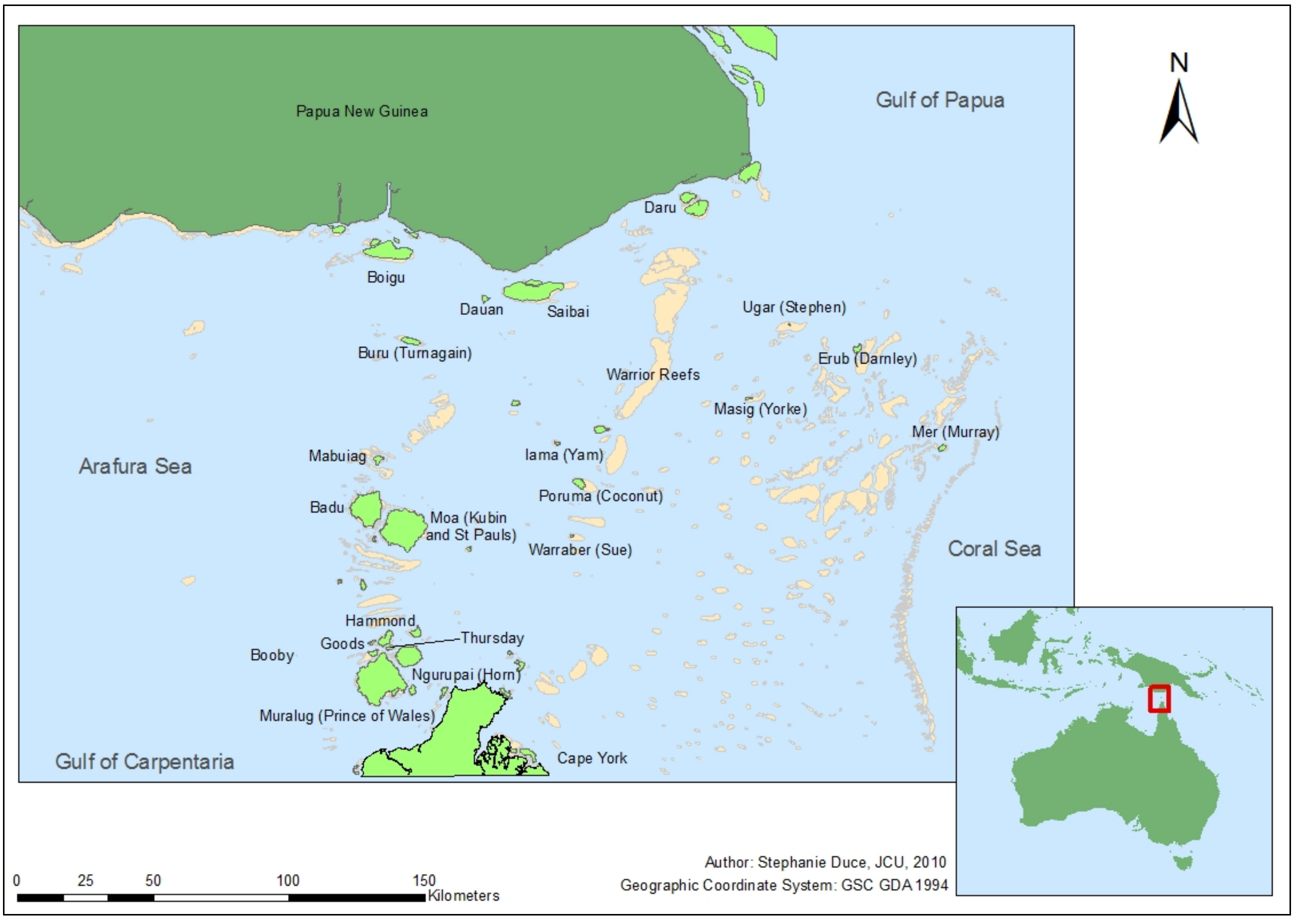

Figure 1.1. Map showing Torres Strait island communities.

2. Synthesis of Coastal Science in Torres Strait

The Torres Strait experiences seasonally reversing winds. Southeasterly trade winds prevail from April to November (called 'Sager' by Torres Strait Islanders). Northwesterly winds, driven by the monsoon, dominate for approximately 15% of the year, from December to March (called 'Kooki' by Torres Strait Islanders) (Brander *et al.* 2004 and SLUP, 2010). Figure 2.1 illustrates the dominance of the southeasterly winds on Thursday Island.

Mean maximum wind speeds up to 15 m/s (54 km/hr) occur in April, May and June during the southeasterlies. Mean wind speeds are also greatest during the southeasterlies, ranging from roughly 7 ms/ to 9 m/s. Wind speeds during the northwesterly months are considerably lower. Maximums range between 10 m/s and 11 m/s, while mean wind speeds are usually less than 4 m/s. Wind speeds are most variable during the transitional months between the reversing wind seasons (March, April, May and November). Wind direction is most variable during the northwesterly months. The strong seasonality of the wind regime in Torres Strait is recognised by many authors to be of fundamental importance to the geomorphic process regimes on the Torres Strait Islands (e.g. Woodroffe *et al.* 2000; Brander *et al.* 2004; Hart and Kench 2007).

Temperatures do not vary much throughout the year due to the tropical location of Torres Strait (approximately 10°S in latitude). The average daily temperature is 29°C, with a mean maximum temperature of 31.2°C and mean minimum temperature of 25.4°C. Sea surface temperature ranges from an average of about 29°C in summer to 25°C during winter. The Torres Strait has a mean annual rainfall of approximately 1,750 mm, most of which falls during the wet, northwesterly (monsoon) season, typically between November and February (Bureau of Meteorology weather statistics at Thursday Island). The dry season generally coincides with the southeast trade winds.

Cyclonic events are relatively rare in the Torres Strait as it is situated to the north of the main cyclone belt. Nevertheless, even relatively distant cyclones pose a substantial threat to the islands particularly when they coincide with high tides (Kaye, 1997, Green *et al.* 2010). Only seven cyclones have occurred in the region since 1910. However, the area does receive storms and strong wind events and can experience the influence of surges from remote cyclones (Kaye, 1997).

2.1 Reef Evolution and Human History

Some coral reefs of the Torres Strait are believed to have been founded during the mid-Miocene and are thus the oldest in the Great Barrier Reef region (Davies *et al.* 1989). Reefs in the Torres Strait have grown on top of the surfaces of reefs formed during the previous Pleistocene interglacial period or over rocky substrates on high islands (Hopley *et al.* 1978; Woodroffe *et al.* 2000). Recent radiometric dating of mollusc shells on Warraber Island indicate that cays in the central islands group may have started forming between 2,450 and 2,750 YBP but may be up to three thousand years old (Woodroffe *et al.* 2007). Archaeologists have found evidence of human settlement dating back 2,500 years but it is likely that the area was inhabited long before this (Burton, 2007).

2.2 Hydrodynamics

Hydrodynamics refers to water movement driven by factors such as tides, waves, currents and wind. Many factors contribute to water level and hydrodynamics in the Torres Strait including tides, sea surface slope, local wind forcing (Wolanski *et al.* 1988) atmospheric pressure, temperature and bottom friction (Lemckert *et al.* 2009). Understanding the hydrodynamics of a region is important to determine larval and sediment transport pathways and rates, and to infer the changes likely to result from climate change and sea level rise (Margvelashivili *et al.* 2008). Two surveys were conducted by Geoscience Australia in 2004 as part of a large program managed by the Cooperative Research Centre for Torres Strait to identify and measure the main physical and biological processes operating in the Torres Strait (Heap *et al.* 2005 and Daniell *et al.* 2006).

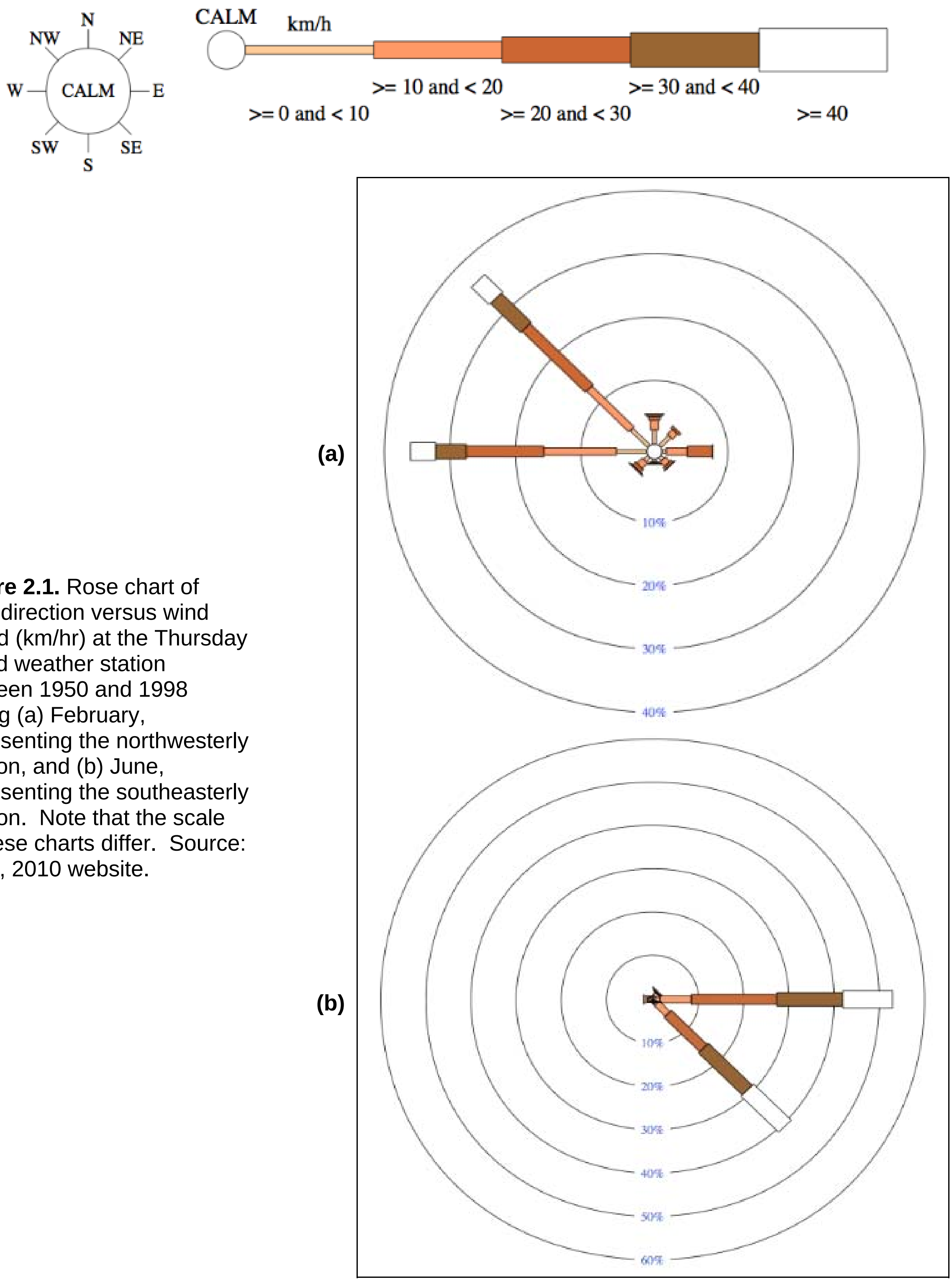

Figure 2.1. Rose chart of wind direction versus wind speed (km/hr) at the Thursday Island weather station between 1950 and 1998 during (a) February, representing the northwesterly season, and (b) June, representing the southeasterly season. Note that the scale of these charts differ. Source: BOM, 2010 website.

2.2.1 *Tidal Regime*

Numerous studies of the tides and currents in the Torres Strait have been conducted (e.g. Wolanski *et al.* 1988, Saint-Cast, 2008, Lemckert *et al.* 2009). Despite this, much remains unknown. The tidal regime of the Torres Strait is complex and varies across the region due to the complex bathymetry in the area (Lemckert *et al.* 2009) and location of the Strait between two ocean basins with different tidal regimes (semi-diurnal in the Pacific/Coral Sea and diurnal in the Indian Ocean) (Brander *et al.* 2004; Hemer *et al.* 2004). The tidal range in the Torres Strait varies from 1.5 m to 6 m in the Gulf of Carpentaria, and from 3 m to 7 m in the Coral Sea and Gulf of Papua (Margvelashvili *et al.* 2008).

The narrow channels between the islands create high tidal current velocities (up to four metres per second in places) (Bode and Mason 1994). These tidal currents can influence the shape of reef flats and islands and are believed to be responsible for the east-west elongation of many Torres Strait reefs (Woodroffe *et al.* 2000; Brander *et al.* 2004).

At present the Torres Strait lacks a suitable height and tide datum system (Lemckert *et al.* 2009). The shortage of long-term sea level observations and the complex, rapidly changing and seasonally variable tidal regime and water level makes it difficult to establish a reliable tidal datum (Metters, 2010). The 'Torres Strait Tidal Survey' conducted by Griffith University in 2007 and 2008 monitored water level, water temperature and ambient atmospheric pressure at sixteen Torres Strait island communities for a minimum of 35 days between 15 May 2008 and 10 July 2008. The study aimed to establish an accurate tidal datum for each area. Data collection was successful at thirteen of the islands: Badu, Boigu, Coconut, Darnley, Hammond, Mabuiag, Murray, Saibai, Stephen, Thursday, Warraber, Yam and Yorke. However, the 35 day data collection period was too short to identify some longer term tidal constituents and seasonal effects on water level. It was concluded that tides in the region varied substantially from island to island and so tides on islands that were not studied could not be predicted accurately (Lemckert *et al.* 2009). The work was corrected by Marine Safety Queensland (MSQ) to take into account seasonal and long-term tidal constituents based on the data from nearby sites with longer water level records. This correction revealed differences of more than 10 cm between calculated and published mean sea levels (MSL) and highest astronomical tide (HAT) for five of the sites studied.

Further complicating the creation of a reliable tidal datum in the Torres Strait are the seasonal changes in water level. Figure 2.2 shows this seasonal fluctuation in mean water level recorded by the tide gauge at Booby Island. Figure 2.4b also shows how water level can vary throughout the Strait over the different seasons based on hydrodynamic modelling conducted by Geoscience Australia (Saint-Cast and Condie, 2006). This seasonal fluctuation is mainly caused by changes in wind patterns and atmospheric pressure and, to a lesser extent, freshwater inflow and rain (Manson, 2009). Substantial variations (>1 m) between measured and predicted tides have been revealed at Goods Island, the site of one of five permanent tide gauges in Torres Strait (Figure 2.3). This demonstrates how important the effects of surge and other factors are on local water levels in the Torres Strait. Surge is discussed in more detail in Section 2.2.4.

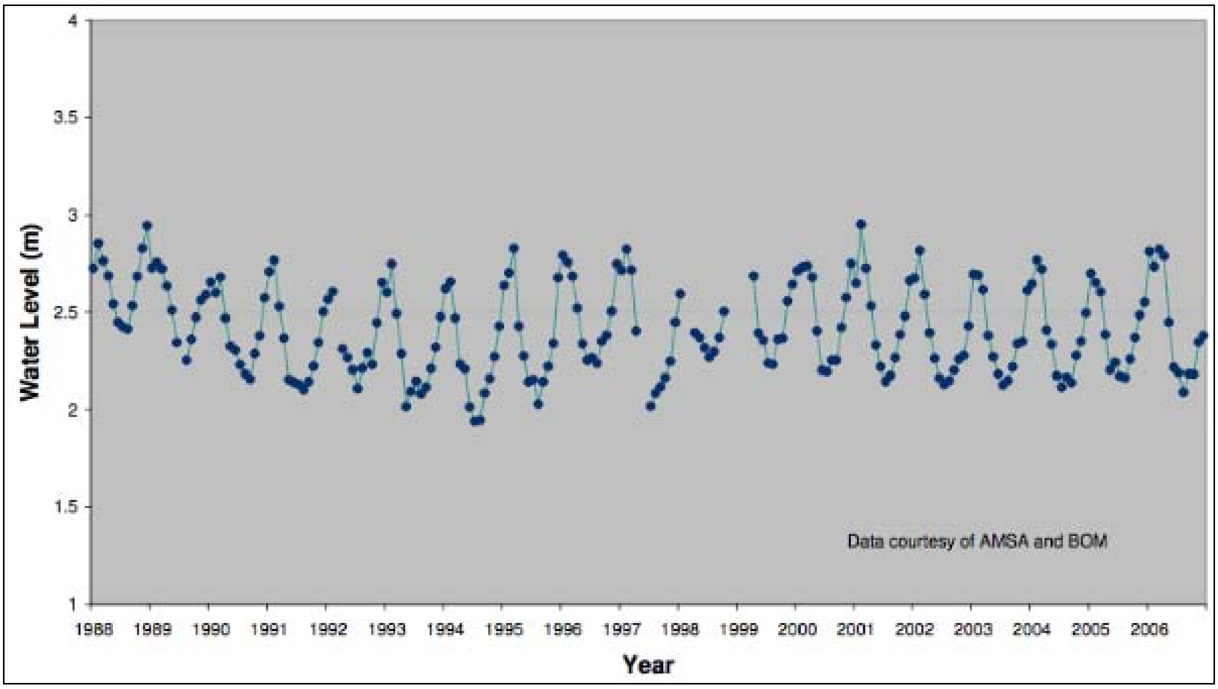

Figure 2.2. Monthly mean sea levels recorded at Booby Island from 1988 to 2006. Source: David Hanslow, TSRA.

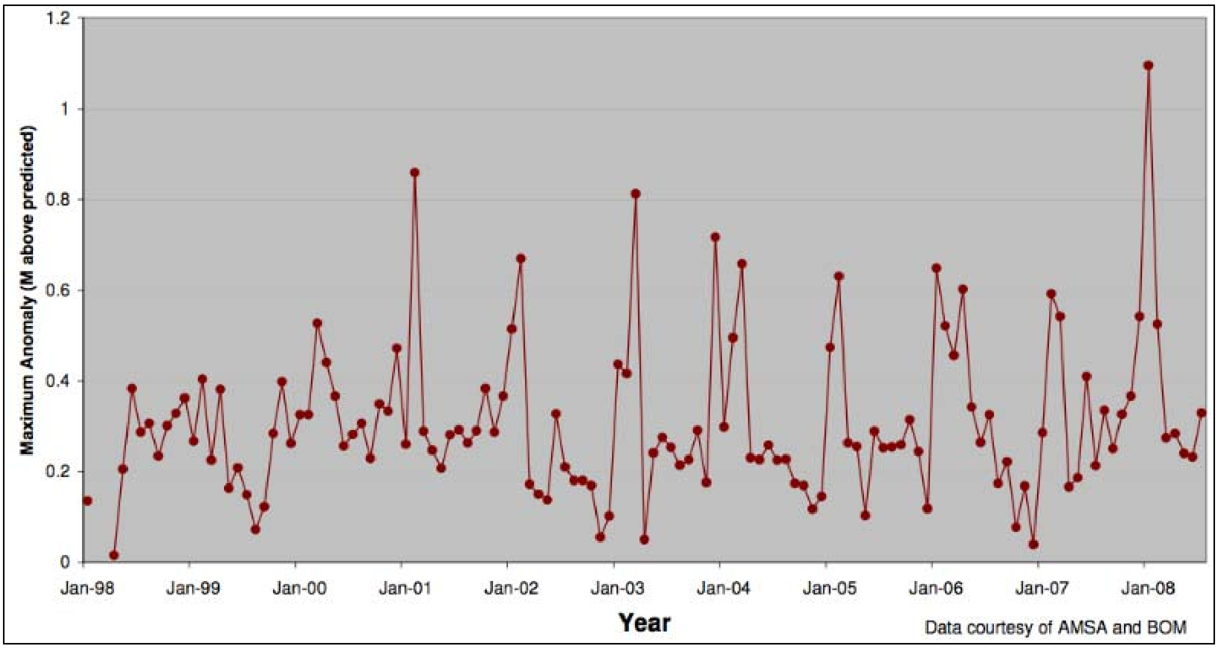

Figure 2.3. Maximum monthly anomalies between measured and predicted tides at Goods Island during the month of January, 1998 to 2008. Source: David Hanslow, TSRA.

2.2.2 Currents

Water currents through the Torres Strait affect sediment transport, turbidity, primary production and recruitment patterns for many organisms and, to some extent, water level. This makes them important for fisheries and shipping in the region. Circulation and currents in the Torres Strait are very complex and have been the topic of numerous studies (Wolanski *et al.* 1988, Bode and Mason 1994, Harris *et al.* 2000, Hemer *et al.* 2004, Heap *et al.* 2005, Saint-Cast and Condie 2006, Saint-Cast 2008, Margvelashivilli *et al.* 2008, Lemckert *et al.* 2009). Waves and tidal currents are responsible for most sediment transport through the Torres Strait (Hemer *et al.* 2004). Wind driven currents, weaker than the tidal currents, also operate in the Torres Strait. These currents also reverse with the winds, moving generally westwards during the southeast trade wind season and eastward during the northwest monsoon season (Hemer *et al.* 2004).

Saint-Cast and Condie (2006) and Saint-Cast (2008) undertook hydrodynamic circulation modelling in Torres Strait. They discovered that the barotropic tide (controlled by the gravitational forces of the moon and sun) was responsible for most instantaneous current patterns but that longer term water transport through the Strait was controlled by the seasonal prevailing winds. During the southeasterly trade winds, a westerly drift dominates, producing seasonal surface currents ranging from 0.2-0.3 m/s, up to 0.6 m/s. This drift was found to weaken to about half the speed and reverse eastwards during the winter monsoon season (Saint-Cast, 2008). The westerly current is stronger and sustained for longer and so results in a net annual transport of water and sediment westward though the Strait (Saint-Cast, 2008).

Saint-Cast (2008) also found circulation in the Torres Strait to be closely linked to that in the northern Great Barrier Reef (GBR) but not to the circulation in the Gulf of Papua. Tidal currents were found to vary in velocity spatially. Depth averaged tidal currents through the Strait were fastest (1.5-3.0 m/s) in shallow water and narrow passages between reefs. Currents also accelerate around islands and reefs (e.g. Mona Islands and the passage through Warrior Reef). Currents were weaker (0-0.5 m/s) in the wake of reefs and islands (e.g. Warrior Reef and the islands of Badu and Horn) (Saint-Cast and Condie, 2006). Surface currents exhibited the same trends but were about thirty percent stronger than the depth averaged currents as they are less affected by bottom friction. Currents during the monsoon season were more variable from year to year reflecting variability in the wind forcing and the timing of the monsoon (Saint-Cast, 2008). Saint-Cast (2008) expects maximum turbidity in the Torres Strait to occur at the end of the monsoon due to fine sediments and turbid water entering from the Gulf of Carpentaria. Turbidity is likely to be lower during the trade wind season as more flushing of the Strait occurs with water from the Coral Sea which has little suspended sediment.

(a)
(b)
(c)

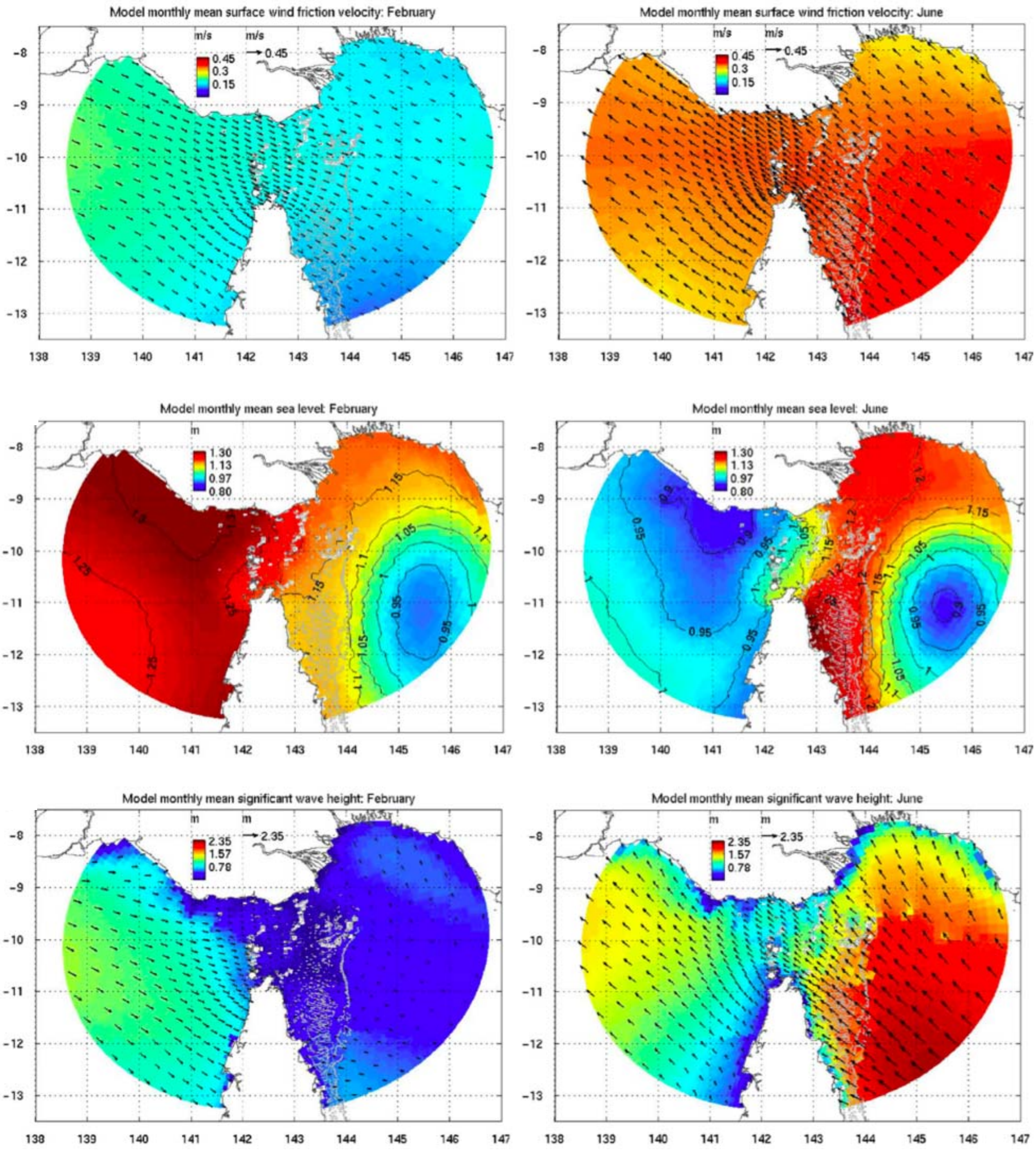

Figure 2.4. Trends in (a) surface wind velocity, (b) mean sea level and (c) significant wave height representative of the monsoon (left) and trade wind seasons (right). Source: Saint-Cast, 2008.

2.2.3 Waves

Understanding wave environments through Torres Strait and around the islands is necessary to understand the formation and stability of reef islands and the causes of erosion and other coastal problems. The wave regime of the Torres Strait varies seasonally and annually (Magvelashivili *et al.* 2008). During the south easterly wind season the Torres Strait is usually protected from long period swell waves generated in the Coral Sea by the northern extension of the GBR. Satellite data shows that significant wave height (SWH) (the average of the highest one third of the waves) is rarely greater than 3.5 m in Torres Strait during the southeasterly season and rarely greater than 1.5 m in the northwesterly season (Hemer *et al.* 2004).

Reef flats and fringing reefs surrounding islands in the Torres Strait alter the characteristics of waves reaching island shorelines. The waves at the shore are of the greatest importance from a coastal management perspective. Wave conditions on reef flats and at island shorelines differ due to the interaction of wind, tide and swell waves with the reef flats or fringing reefs surrounding islands. The nature of the interaction depends on the tidal stage and the geomorphology of the reef flat (Samosorn and Woodroffe, 2008).

The nearshore and reef flat wave environments surrounding Warraber Island have been measured during the predominant south-easterly wind season by Brander *et al.* (2004) and Samosorn and Woodroffe (2008). These studies found that water depth, and thus tidal level and reef flat elevation, strongly influenced the characteristics and energy of the waves reaching the island shoreline. Samosorn and Woodroffe (2008) found waves on the windward side of the island to be larger and shorter period than those on the leeward side. The wave environment on the reef flat was found to be dominated by off-shore wind waves driven by local wind conditions (Brander *et al.* 2004). They found that very little wave energy on the reef platform and island shoreline came from ocean swell (with periods of 8-20 seconds) or long period infragravity waves (>20 seconds). Brander *et al.* (2004) suggested that normal wave conditions were such that very little sediment transport would occur on the island beaches. Thus, significant change is only likely during extreme events. This is primarily due to the tide being high for only short periods and the relatively low probability that high tides and large waves coincide.

However, it is recognised that a substantial amount of sediment can move over short periods. Most hydrodynamic studies in the Torres Strait have collected data only during the southeasterly wind season. Data collected on the cay islands of Warraber, Poruma and Masig (see supplementary report: Parnell *et al.* 2010) shows that although southeasterly waves dominate over the majority of the year, waves generated during the shorter and generally less intense northwesterly wind season are particularly significant for sediment transport. The reef flats on the northern side of the islands are generally much narrower and lower (by up to roughly one metre) than the reef flats on the southern side of the islands. Thus, during the northwesterly wind season waves capable of moving sediment penetrate to beach at the northern side of the islands much more frequently. This is because wave height is limited by water depth (typically wave height will be less than approximately 0.55 times water depth (Brander *et al.* 2004; Hopley *et al.* 2007) and deeper water allows larger waves to reach the shoreline. Data collected during both wind seasons showed maximum wave heights on the northern shores approximately two times (up to 1.43 m) those on the southern shores in the respective wind seasons. The two wind and wave seasons are also important with respect to island dynamics with seasonally reversing sediment transport evident on all the cay islands. A similar pattern exists on the northern side of Iama (in the vicinity of the village), where the shorter but more intense northwesterly wind and wave season balances the longer but less intense (due to orientation) southeasterly wind and wave season with respect to sediment transport. There have been no studies of wave characteristics on the island shorelines at any locations other than Warraber, Poruma, Masig and Iama.

2.2.4 Surge Events

An elevation of mean water level due to a combination of pressure set up (approximately one centimeter per 1 hPa of pressure) and wind set up (a ‘piling up’ of water against the coast due to onshore winds) is generally referred to as *storm surge*. Storm surges frequently result from low pressure systems in the vicinity of the coast and are particularly severe under tropical cyclone conditions. Maximum storm surges occur in the forward left quadrant as a tropical cyclone crosses the coast and, on the Queensland coast, have in the past reached confirmed levels of five metres above HAT (with anecdotal evidence suggesting levels of about thirteen metres) in Princess Charlotte Bay during Tropical Cyclone *Mahina* in 1899 (Nott and Hayne, 2000). The magnitude of storm surges depends on a range of factors including the magnitude and horizontal extent of the event, the speed with which the low pressure system is travelling and the configuration of the shoreline. Storm surges on islands and reefs (such as those on the GBR) tend to be much smaller than those on mainland shores due to the ability of water to move around the features rather than being held against the shoreline. A discussion of storm surge on the north Queensland coast can be found in Hopley *et al.* (2007).

Torres Strait receives few topical cyclones (due to its latitude) and classic ‘wind set up’ is small due to the nature of the environment. However surge events do occur, typically driven by meteorological events occurring some distance away, and these may raise mean water levels substantially for periods of time. One mechanism for a surge event is water being driven into the Torres Strait by clockwise rotating winds from a tropical cyclone in the Gulf of Carpentaria. This extra water may be blocked from moving out of Torres Strait by the dense reef systems at the eastern side of the Strait, or by tidal currents, leading to significant increases in water surface elevation. Most significantly, a surge event occurring during the summer months, coinciding with higher than normal spring tides (king tides) particularly from December to March, as well as high winds and high waves, causes significant problems of erosion and inundation in many locations. Surge events which have occurred previously, for example in 1948, led to some residents of the northwestern islands moving permanently to settlements on Cape York Peninsula. Similar events have been described by elders living on other islands. Surge events coinciding with higher than normal tides during the winter months are far less common but there is anecdotal evidence that inundation events have occurred.

Surge events during summer high tide periods have been widely reported over the past few years. This may be simply an unusual set of events, or it may be that wide coverage has meant that problematic events are being more systematically recorded and reported. Alternatively, an increased frequency of events (perhaps due to climate change) is possible. It is certain, however, that management and adaptation processes must be put in place to manage these events due to the fact that they result in the most significant inundation. They also have the potential to cause significant erosion due to increased water depths across the reef flats allowing higher waves to reach the beach. Surge events that increase mean water levels for periods of time must also be understood if an adequate tidal datum is to be established.

Figure 2.3 shows the significance of surge events (data collected at Goods Island and analysed by David Hanslow, TSRA), and the maximum monthly measured anomalies (that is, the highest water levels above the tidal prediction). Over the period 1998 to 2008 there are many significant anomalies, almost all of which occur in the first few months of the year, in a period potentially coincident with king tides. The highest anomaly, 1.15 m, was recorded in January 2008. Fortunately it did not coincide with king tides. If it had, inundation levels would almost certainly have been the highest on record. Another significant event that lasted over a number of days occurred in January 2009 (Figure 2.5), coinciding with a period of king tides. Although the maximum anomaly was 0.94 m, the highest anomaly coincident with high tide was approximately 0.6 m.

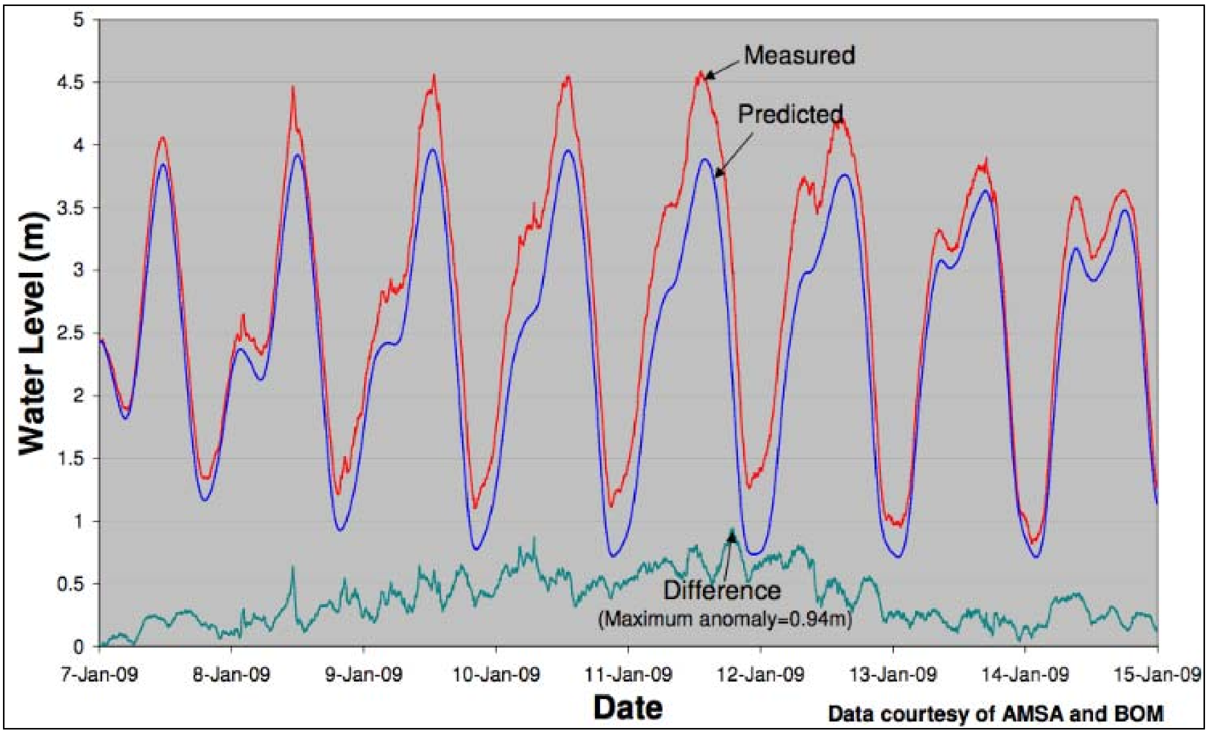

Figure 2.5. Goods Island water levels recorded over a king tide period in January 2009. Source: David Hanslow, TSRA.

2.3 Sedimentary Environment

The Torres Strait is a geological mixing zone of terrigenous and calcareous sediments (Hemer *et al.* 2004). Terrigenous sediments are mainly released into the Strait from rivers in PNG while the calcareous sediments are locally produced on reefs. The distribution of different sediments and sedimentary landforms is controlled by location (i.e. proximity to river mouths or reef flats) and hydrodynamic processes which transport and deposit sediments. Muddy terrigenous sediments dominate in low-energy depositional areas, across the front of the Fly River Delta and in the eastern section of Torres Strait between the numerous reefs (Hemer *et al.* 2004). Heap *et al.* (2005) documented large sand waves on the seabed, the movement and migration of which is believed to be controlled by the seasonal winds.

Sediment transport modelling conducted by Margvelahvili *et al* (2008) suggested that tidal mixing, storm events and seasonally varying through-flow result in a net export of sediments from the Torres Strait. They note however that the bio-production of sediment, coastal erosion and input from rivers during floods are likely to offset the export of sediments from the area.

The sedimentary environments of reef platforms and fringing reefs are highly important as they provide sediment for most island beaches (except on the mud islands of Saibai and Boigu). Carbonate production by organisms like corals, algae and other benthic organisms (e.g. foraminifera) and mechanical and biological erosion on reef platforms create sediments which are either stored on the reef, transported to deep water sinks off reef or transported to build islands and beaches (Hart and Kench, 2007).

2.4 Island Dynamics

Studies of island dynamics have been restricted to cursory studies of six islands (Boigu, Saibai, Masig, Poruma, Warraber and Iama) undertaken by the Queensland Environmental Protection Agency (EPA) (now Department of Environment and Resource Management), detailed studies of the islands of the central group (Masig, Poruma, Warraber and Iama) undertaken by James Cook University (JCU) in collaboration with the TSRA and local communities, and a number of other studies on Warraber. The EPA studies conducted rapid assessments of shoreline erosion problems and suggested mitigation options based on short site visits and a review of historical data. The JCU research provided a detailed understanding of island dynamics based on historical records, and surveys and process studies undertaken over both wind seasons. The objective of the JCU studies was to provide the communities with options for mitigation and adaptation to erosion and inundation problems that were achievable and sustainable, working with natural processes. The consequences (some of which were undesirable) of each of the options were also presented. The detailed results of these studies are presented in the supplementary report.

The coastal geomorphology of the high island reefs and beaches has received no attention, despite the low-lying areas of the islands being the focus of much of the infrastructure of the Torres Strait communities. The concentration of research effort on the six islands of the central and northwestern groups reflects the perceived urgency and importance of coastal problems on these generally low-lying islands by the Torres Strait leaders. It does not mean that the other islands were not seen as having issues related to coastal inundation and erosion that needed to be addressed.

In the following descriptions, EPA reports have been used for Boigu (Figure 2.6) and Saibai (Figure 2.7), and JCU research for Masig (Figure 2.8), Poruma (Figure 2.9), Warraber (Figure 2.11) and Iama (Figure 2.13). The highlighted areas are those locations on the islands that are of particular concern to the locals with respect to coastal issues. The supplementary report provides full documentation of the results for the Central islands.

2.4.1 Boigu

Figure 2.6. Aerial view of Boigu Village. Source: EPA Rapid Assessment.

Boigu is close to the PNG mainland, adjacent to the Mai River mouth. The island (approximately 10 km by 5 km) was formed primarily from sediments derived from the PNG mainland that were deposited over an old coral platform. Only a very small part of the island is above HAT. The village (up to two metres above HAT) is on a raised area on the northern part of the island where coarse sediments have accumulated. Inundation of some parts of the village is common on high tides, particularly when combined with a surge event, with water intrusion from all sides of the village possible. The shoreline on the seaward side of the island has a concrete block revetment and rock seawall, parts of which have replaced or overlie older revetments. The revetment and seawall have both been overtopped by water at various times. At the western end of the village and in the vicinity of the cemetery (Site 1 in Figure 2.6), a narrow beach changes seasonally, while long-term erosion is not indicated except at the end of the rock seawall. However, the close proximity of grave sites to the episodic erosion scarp is of concern and extension of the shoreline works is probably warranted. The seawall that exists along the village shoreline (Site 3, Figure 2.6) is generally functional with respect to erosion protection although some areas are in disrepair and may not have stable foundations (Site 2, Figure 2.6). It is, however, too low with respect to inundation events.

2.4.2 Saibai

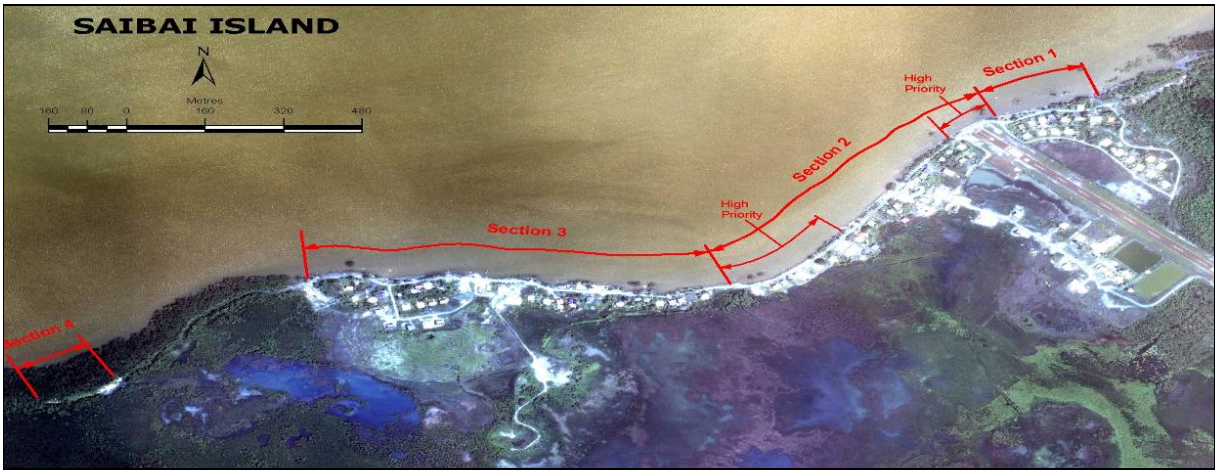

Figure 2.7. Aerial view of Saibai Village. Source: EPA Rapid Assessment.

Saibai is close to the PNG mainland, southwest of the Fly River delta. The island formation is similar to that of Boigu. The village on Saibai Island is on a raised narrow ridge about three kilometres in length in the northwesterly part of the island. The ridge is comprised of coarser sediments than those typically found elsewhere on the island and terminates at each end in sand spits sheltered behind mangroves. The western and eastern parts of the village face north, with the central section facing directly into the prevailing northwesterly winds and waves that occur over the summer months. The village is less than two metres above HAT. Seawalls have been constructed along almost the entire length of the village. Depending on the foundations, parts of the seawall are in reasonable repair, with other sections being undercut, or else collapsed or toppled. East of the airstrip (Section 1 in Figure 2.7) the wall is in reasonable repair and is functional with respect to erosion protection. In Section 2 (Figure 2.7), parts of the wall are in reasonable repair, but in two areas (in the vicinity of the airstrip and at the southwestern end) the seawall is in poor repair, with toe undercutting and collapse. Parts of the seawall are in urgent need of replacement or repair. The shoreline at the western end of the village (Section 3, Figure 2.7) is a series of beachrock outcrops with small embayments of mud and sand in between. Meandering seawalls built on beachrock follow the natural alignment of the coast, along most of the section. There has been some construction of seawalls in the intertidal zone with reclamation. Erosion is not generally a problem in this section (due to the beachrock foundations), with seawall construction probably for inundation control (although there is little height consistency). In the vicinity of the cemetery (to the west of the village), seasonal erosion and deposition occurs on a small beach located behind mangroves. Grave sites are threatened due to their proximity to the coast.

2.4.3 Masig

Figure 2.8. Aerial view of Masig, with areas of concern indicated.

Masig Island is situated on the northwestern edge of a reef platform which it shares with the uninhabited island of Kodall. A series of intertidal sand banks top the reef flat between the islands. The level of the reef flat varies by up to approximately one metre, with the lowest levels on the northwestern side and the highest levels on the southeastern corner. The reef flat on the northwest is very narrow. The highest and oldest parts of the island are also on the northwestern side. The village is centered on the lower, eastern end of the island, although other community infrastructure (harbour facilities, rubbish dump, water facility) is situated elsewhere on the island. A hard-rock jetty on the northern side of the island acts as a groyne, and there is substantial erosion to the east and accretion to the west. A sand berm exists around most of the island, deposited during times when waves have overtopped the top of the beach (a common island building process on coral cay islands). There are significant outcrops of beachrock to the west of the jetty, and these are further exposing due to the erosion that is occurring.

There are good records of shoreline change for Masig since 1974. There have been areas of erosion, but almost equal areas of accretion with little change in net island area. The most significant change in the shoreline position has been caused by the construction of the island harbour and jetty in 1992. The distribution of sand on the beach and the beach sediment transport processes are both seasonally reversing within the context of the long-term trends. However, the jetty, acting as a groyne, has disrupted this pattern leading to a significant shoreline offset. There is no evidence that significant quantities of beach sediment are leaving the island through the harbour channel. However, sediment is leaving the reef flat and island at the north-western tip, and is being deposited in a sand bank off the reef flat.

Waves recorded over the reef flat were typically less than 0.75 m during both wind seasons (on the respective sides of the island). Sediment transport on the beach (above the level of the reef flat) was very significant during periods of high waves, but was also occurring during periods where waves were as small as ten centimetres. However, due to wave action being confined to periods around high tide and due to the limiting effect of water depth (described in Section 2.2.3) the period during which transport occurs is limited.

Inundation is of particular concern on Masig. The village is situated on some of the lowest parts of the island and flooding already occurs during summer king tides and is exacerbated during surge events. Even small amounts of sea level rise will cause significant periodic flooding of large sections of the village.

Figure 2.8 shows the areas identified as of particular concern to the Masig community. These include areas of erosion (Sites A, C and E), and areas where inundation and water intrusion is of particular concern (Site B and Site D, in the vicinity of the cemetery). The community identified the area to the east of the jetty as being of highest priority with respect to erosion and a sand bypassing project has been proposed, with the replacement of the jetty with an open piled structure being favoured in the long term, so that natural sediment transport pathways can be restored.

2.4.4 Poruma

Figure 2.9. Aerial view of Poruma, with areas of concern indicated.

Like Masig, Poruma (Figure 2.9) is also situated on the northwestern corner of the reef flat, where the reef flat is narrow and lower than around the rest of the island. Poruma is a long and narrow island, with an unusual sand dune on its southern side, possibly indicating that the island beach was previously more extensive. The island surface on Poruma is also generally higher than on Masig or Warraber, so that inundation events are likely to be less frequent.

Poruma village is situated near the western end of the island, and with the exception of the airport runway, there is little infrastructure (the rubbish dump and a gazebo) at the eastern end of island.

The southern shoreline to the east of the village has been generally eroding since 1974. The northern shore to the east of the village and airport runway has been stable or accreting. The western end of the island has undergone significant change over the period since 1974 so that the shoreline configuration is now quite different. In summary, there was accretion on the southern side and erosion on the northern side between 1974 and 1999. Since 1999 there has been major erosion on the southern shore, with the shoreline retreating further inland than it was in 1974, and accretion on the northern shore, to a position approximating the 1974 shoreline. Overall, the effect has been a significant loss of area and a rounding of the eastern tip of the island that was once a prominent spit like feature. A significant intertidal sandspit joins the end of the island. It changes its morphology seasonally, 'wagging like the tail of a dog', moving north during the southeasterly wind season, and south during the north-westerly wind season.

The jetties associated with the harbour have disrupted alongshore sediment transport, leading to long term erosion to the east and accretion to the west, although this is seasonally reversing. The channel does not act as a conduit for sediment leaving the island beaches.

However, significant sediment leaves the reef flat to the north-west, primarily driven by south-easterly waves, accumulating in a large sand feature off the reef flat (Figure 2.10).

Waves over one metre were recorded on the respective reef flats during the recording periods during both northwesterly and southeasterly wind seasons. Sediment transport and areas of cut and fill on the reef flats are seasonally reversing. Sediment transport on the beaches is driven by waves but is limited by water depth to high tide periods.

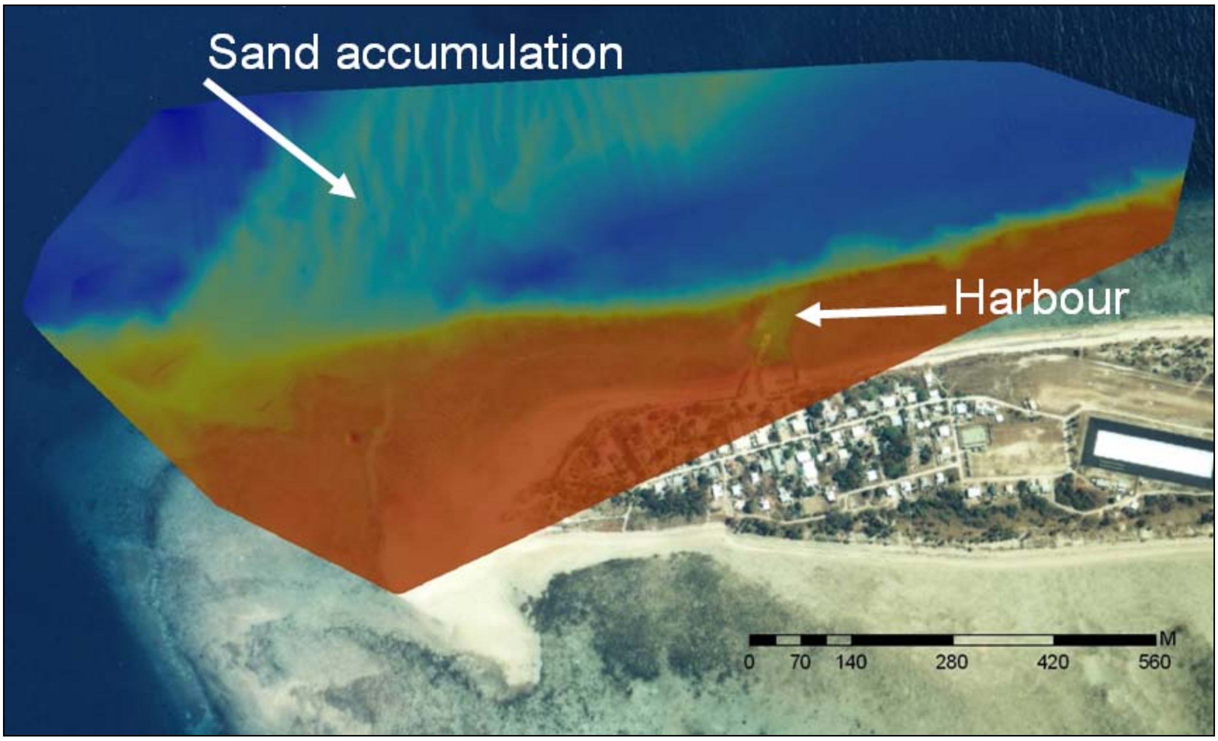

Figure 2.10. The western end of Poruma Island, showing a sand accumulation off the reef flat. Similar sand bodies can also be found at Masig and Warraber.

The areas of particular concern to the Poruma community are identified in Figure 2.9. The southern shoreline is eroding, but there is a substantial dune providing a buffer. The eastern tip of the island has a popular gazebo that may have to be move due to erosion problems. The area to the east of the jetty is eroding in the long term, and a relatively recently constructed road may eventually have to be abandoned or protected by a seawall. The eastern tip of the island is of most concern to the community, particularly as it is the location of the Poruma Island Resort. Protection of the resort area using a seawall is the management option favoured by the community, despite the negative consequences in the form of the loss of the supratidal and intertidal beach on the southern side of the area affected.

2.4.5 Warraber

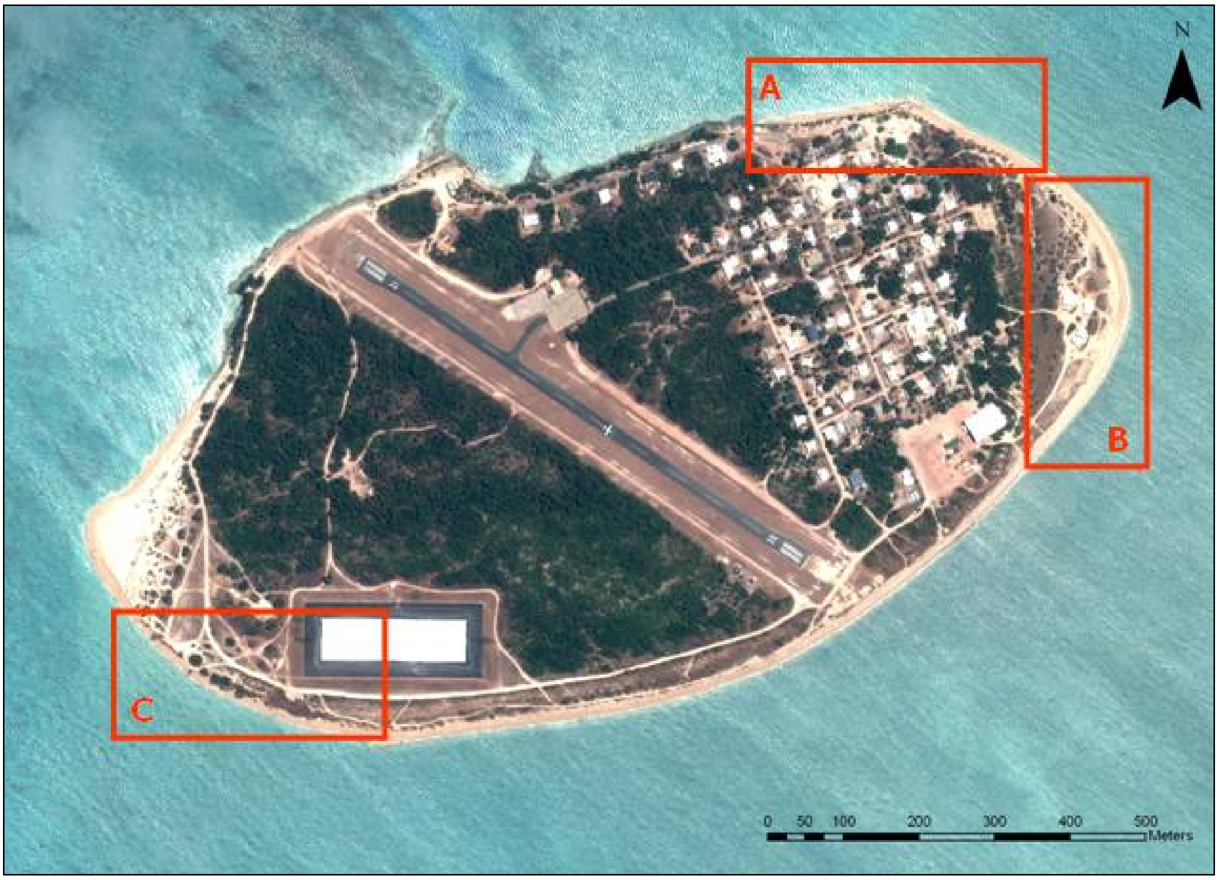

Figure 2.11. Aerial view of Warraber, with areas of concern indicated.

Warraber Island is also situated on the northwestern reef platform, and like Poruma and Masig, the reef flat level on the northwestern side of the island is lower than on the southeastern side. However, unlike the other two islands, the reef flat is reasonably wide on that side. Warraber has been the subject of a range of scientific studies (Woodroffe *et al.* 2000; Hart, 2004; Brander *et al.* 2004; Samosorn, 2006; Hart and Kench, 2007; Leon and Woodroffe, 2007; Woodroffe *et al.* 2007; Samosorn and Woodroffe, 2008), covering island dynamics as well as island evolution. These studies have shown that Warraber first appeared around three thousand years ago and has built out constantly since (Samosorn, 2006; Woodroffe *et al.* 2007; Hopley *et al.* 2007). The initial sand accumulation occurred when sea level was about one metre higher than it is now and this area remains as a higher part of the island with significant areas of elevated beachrock. Recent sand deposits over the last few decades can be seen at the northeastern and southwestern ends of the island (Figure 2.12).

The village of Warraber is at the eastern end of the island, extending in parts towards the higher and older island core. The harbour facility and the northwestern end of the airport runway are situated on or adjacent to the higher part of the island and are relatively secure, being built on consolidated beachrock. Some parts of the village are very low, particularly in the vicinity of the resort, which is built on sediments that have accumulated since the mid 1960s. The water facility is situated on the south-western corner of the island.

Much of the northwestern and northern shores of the island consist of elevated beachrock, which extends to the reef flat. East of where the beachrock terminates, the shoreline is eroding and has been protected by a rock seawall (parts of which are failing) and a number of large tyres, which have been doing a reasonable job at holding the northeastern corner of the island. Aerial photograph evidence shows that since 1966, the northeastern and southwestern corners of the island have eroded significantly, by up to about one hundred metres, and sediments have been deposited further to the east and to the west respectively. The island therefore gives the appearance of rotating clockwise. The southern shore of the island is relatively stable, although parts are very low and subject to inundation, so that maintenance of the supra-tidal berm is critical. As on the other cay islands, sediment movement and beach cut and fill are seasonal, within the context of the long-term 'rotation' trend.

A significant northwesterly storm event was captured during data collection in late January and early February 2007, during a period of high tidal range. Waves reached a maximum height of approximately 1.4 m, with a period of about five seconds. Wave height was limited by water depth with the pattern of wave height over the tidal cycle mirroring the reef flat water depth (at a ratio of about 0.5-0.6). These conditions are likely to be close to the maximum height of waves that will be experienced at the shoreline under current sea levels, due to depth limiting. The direction of travel of the waves was almost parallel to the shoreline at the ends of the island, and resulted in erosion and very significant sediment transport towards the south. Due to the depth limiting effect, wave heights on the southern shore are never likely to be as large as those on the northwestern shore.

The areas of particular concern to the community are identified in Figure 2.11. The north-eastern corner of the island is eroding and is low (leading to inundation events) in the vicinity of the cemetery and a site where a new church building is planned. Tyres on the shoreline have held the shore reasonably well, although a repaired and extended seawall in the area is the community's preference, despite the almost certain consequence of beach degradation. The erosion on the southwestern corner of the island is of concern, primarily due to its proximity to the water facility. Although the facility is still some distance from the eroding shoreline, continued erosion may necessitate further action in the medium term. The resort area (Site B in Figure 2.11) is situated on low lying sediments deposited since the mid 1960s. As the area is currently accreting, there is no immediate concern in relation to erosion, unless recent trends reverse.

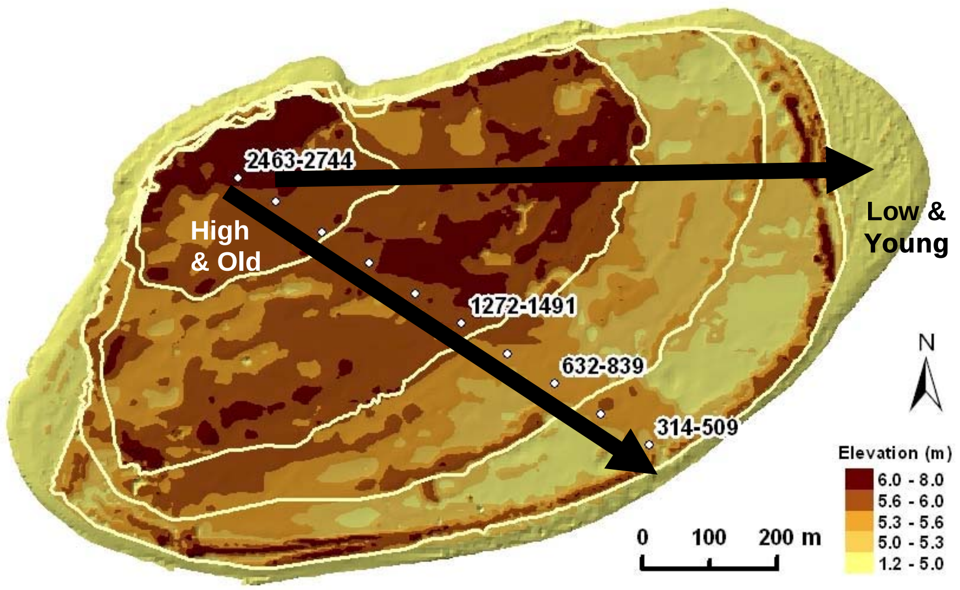

Figure 2.12. The development of Warraber Island, based on morphology and radiocarbon dates (Woodroffe *et al.* 2007).

2.4.6 Iama

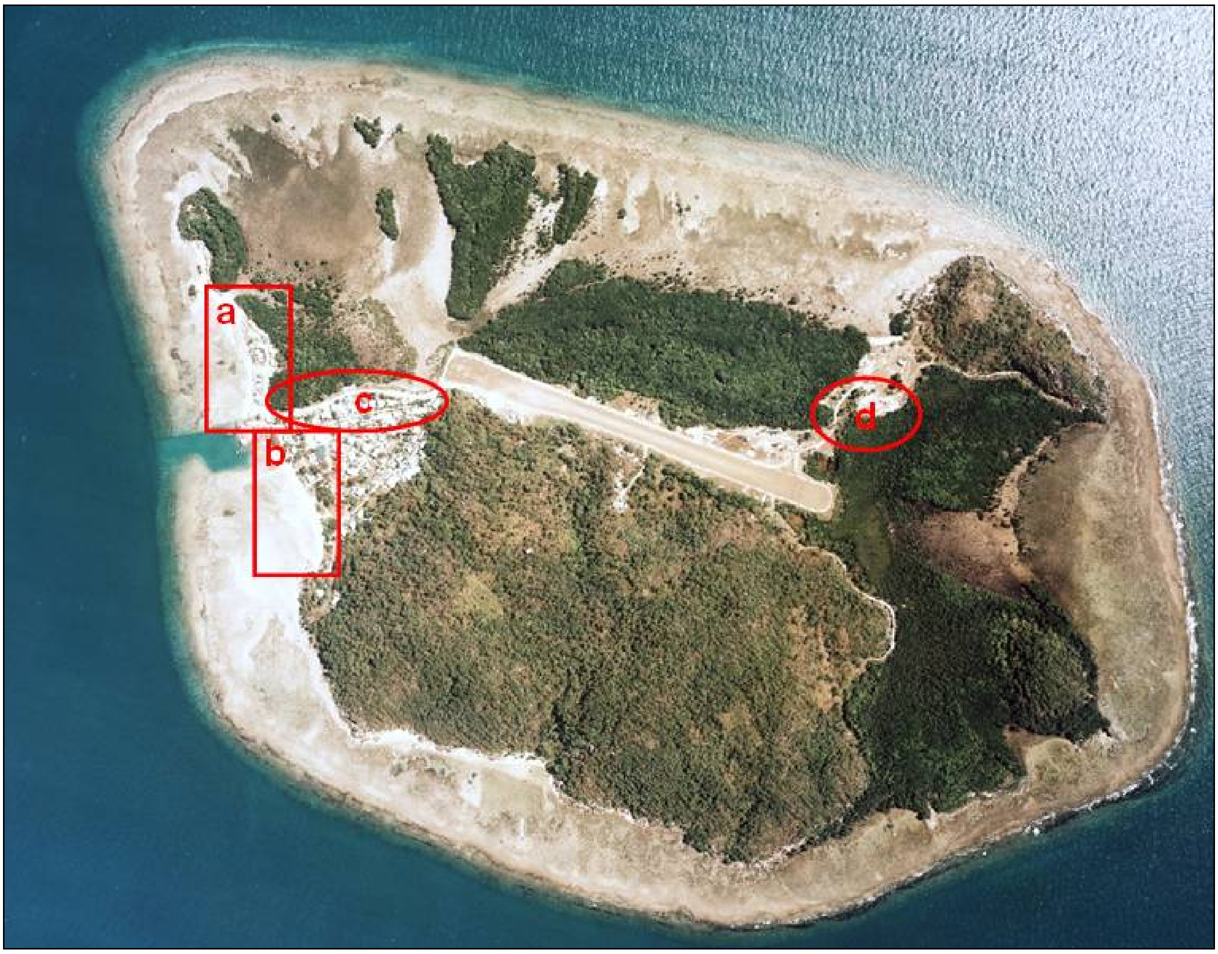

Figure 2.13. Aerial view of Iama, with areas of concern indicated.

Iama is a high continental island in the central group. Aerial photographs give the impression that the island is much larger than it really is, due to the presence of large areas of mangrove forest on the reef flat on the northern and western sides of the island. The village is situated on a relatively low, triangular shaped area of sediments on the western side of the island, extending into the lower parts of the central hills. A low and narrow sandspit extending from the jetty towards the north forms part of the village. Significant areas of cemented coral rubble occur on the reef flat to the north of the spit. The cemetery, the sewerage works, rubbish dump and some recreational facilities are located adjacent to mangrove forests on the northern side of the airstrip. The power station, health centre, various work sheds and a new residential area are situated on the southern side of the airstrip. Despite appearing to have a large land area, reasonable building sites are limited due to topographical constraints.

The village, located adjacent to the main beach and to the south of the jetty, is comprised of terrigenous and carbonate sediments. There is a supratidal berm along the length of most of the beach, but it is breached near the centre of the beach by a creek. For most of the year the creek is impounded by a berm, which breaches to discharge water during wet periods. Towards the south of the beach, a seawall has been constructed to protect the road. Sediment transport and beach cut and fill cycles are seasonal, with sediments moving south during the northwesterly wind season and north during the southeasterly wind season. Since 1974 (the date of the first aerial photographs), there has been net accretion at the southern end of the beach and relative stability elsewhere. The beach is an essentially closed sediment system, so any losses of sediment are likely to cause erosion.

Inundation of the village along the ‘Back Road’, on the northern side of the village extending from the beach to the airstrip along the end of the mangroves, is relatively frequent. A poorly maintained low wall has had little effect. The northern spit area has a seawall extending along its length. Inundation from the rear and wave overtopping on king tides occurs frequently leading to significant problems for residents.

Storm waves were not recorded during data collection during the northwesterly wind season, but maximum heights of around 1.5 m are likely, based on data collected at Warraber. Wave heights a little over one metre were recorded. Despite its westward-facing orientation, waves during the southeasterly wind season penetrate the bay, refracting around the southern point. Waves of up to one metre were recorded in September and October 2007.

The areas of significant concern to the community are indicated in Figure 2.13. The main beach area does not have significant issues of erosion currently, but monitoring needs to continue. Despite a long-term plan to move residents from the spit area to other accommodation, the community would like to explore the option of a reef top breakwater that would provide protection and also provide safe boat mooring during the northwesterly wind season. A higher and well constructed wall is required to stop inundation along the back road. Inundation in the vicinity of the sewerage works and the rubbish dump may also need to be addressed. Inundation may also start to affect the cemetery area if there is significant sea level rise.

3. Climate Change in the Torres Strait

Earth's climate is constantly changing. However, records show that at present its climate is warming and that human (anthropogenic) activities have increased the rate of this warming due to a phenomenon that has been popularly called the 'greenhouse effect'.

Since the industrial revolution in 1750 the concentration of greenhouse gases such as carbon dioxide, methane and nitrous oxide has increased in the earth's atmosphere. Over the same period global average air and ocean temperatures have increased, global average sea level has risen and there has been widespread melting of snow and ice (IPCC, 2007). These effects are predicted to continue and are likely to have severe environmental, economic and social impacts in the future. The Intergovernmental Panel on Climate Change (IPCC) is a scientific body established 'to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences' (IPCC, 2007).

The following changes are predicted to result from climate change (IPCC, 2007):

- Warmer average global air and ocean temperatures;
- Average global sea level rise;
- Ocean acidification; and
- Regional changes in wind patterns, precipitation, extreme weather events and sea ice.

3.1 Climate Change Modelling and Scenarios

Computer models are being used to determine where changes are likely to occur and the rate at which they are likely to occur. Models allow scientists to predict how systems will behave under different climatic conditions produced by different greenhouse gas emission scenarios. To overcome uncertainty surrounding the amount of greenhouse gas that will be released by human activities in the future, the IPCC created different scenarios based on different rates of greenhouse gas emission and different levels of climate sensitivity to these emissions (Nakicenovic and Swart, 2000).

A good understanding of Earth's natural processes, along with good data, is needed to create accurate models. As Earth's natural systems are very complex and vary over space and time, the outputs of models have some degree of uncertainty. In addition, modelling is usually done at a global or regional scale and may not always represent local conditions very well. Nevertheless, the Global Climate Models (GCM) used by the IPCC and smaller scale regional climate models provide robust guidelines about the type and rate of changes that are likely to occur in future.

In addition to the broad scale global and regional modelling results presented by the IPCC, some elementary modelling has been conducted at higher resolution for Cape York Peninsula (Dunlop and Brown, 2008) and Torres Strait (Sharing Knowledge, 2008). Suppiah *et al.* (2007) performed regional modelling of climate change for mainland Australia including Far North Queensland. The CSIRO and Australian Bureau of Meteorology (BOM) (2007) produced a report on climate change in Australia which also predicts climate change and sea level rise until the year 2070 for the Queensland region. The Torres Strait is included in regional modelling conducted by the CSIRO to determine the implications of climate change in the Asia/Pacific Region (Preston *et al.* 2006). The CSIRO is currently performing higher resolution (approximately 25 km) modelling, covering the Torres Strait region, for future emission scenarios (Green *et al.* 2010).

To take into account uncertainty about future rates of greenhouse gas emissions the IPCC has created six different emission scenarios, ranging from high to low global emissions, to be used in climate change modelling (Nakicenovic and Swart, 2000). The most relevant predictions of climate changes for the Torres Strait region available to date are presented below along with their probable direct and indirect impacts and possible adaptation and mitigation strategies.

3.2 Projected Changes in Regional Climate

According to the Bureau of Meteorology's Annual Australian Climate Statement, 2009 was the second warmest year since high quality records began in 1910 (Bureau of Meteorology, 2010). Scientists are now sure that global mean temperature increases observed over the past few decades are caused by human burning of fossil fuels and deforestation (Allison *et al.* 2009). The phenomenon of anthropogenic global warming is predicted to continue. Average temperature in the Cape York and Torres Strait region is predicted to increase by between 0.3°C to 1°C by the year 2030, and 1°C to 4°C by 2070, relative to the climate of 1990 (Watterson *et al.* 2007). Modelling conducted by the CSIRO and Bureau of Meteorology also suggests that 'hot spells' – three days in a row with temperatures above 35°C – are likely to increase from six to 50 days by 2070 (Green *et al.* 2010). Downward solar radiation is also predicted to increase by up to ten percent by 2070 (Watterson *et al.* 2007).

The IPCC (2007) is uncertain how the Australian Monsoon and El Niño-Southern Oscillation (ENSO) will respond to climate change and thus are uncertain how climatic conditions like wind, rainfall and cyclone events will change in northern Australia and Torres Strait in the future. Models vary in their prediction of changes to the Australian monsoon (Meehl *et al.* 2007). Dunlop and Brown (2008) suggest an increase in storm intensity is likely for the Cape York Peninsula region.

Modelling conducted as part of the Sharing Knowledge Project (2008) suggests that by 2070 the wet season rainfall in Torres Strait will be 0.8% to 13.2% higher than 1990 levels, while the dry season range of rainfall is expected to be 23.1% to 3.9% below 1990 levels. Thus, greater variability between seasons is likely. Evapotranspiration rates in the region are also predicted to increase by up to 16% by 2070, causing a larger moisture balance deficit and a drier environment generally (CSIRO and BOM, 2007).

Future changes in average wind speed are difficult to model with certainty. The Climate Change in Australia Report indicates that wind speeds in coastal areas are likely to increase by a best estimate range of 2% to 5% by 2030 (Figure 3.1). These trends are expected to continue and increase by 2100 (CSIRO and BOM, 2007). Wind direction is very important to processes such as coastal erosion and storm surge. However, likely changes to the direction of winds have yet to be predicted (CSIRO and BOM, 2007). Future changes in tropical cyclone and storm activity cannot be predicted with any certainty; however observational data confirm that cyclone intensity has increased over the past thirty years. This has been linked to warmer sea surface temperatures (Allison *et al.* 2009).

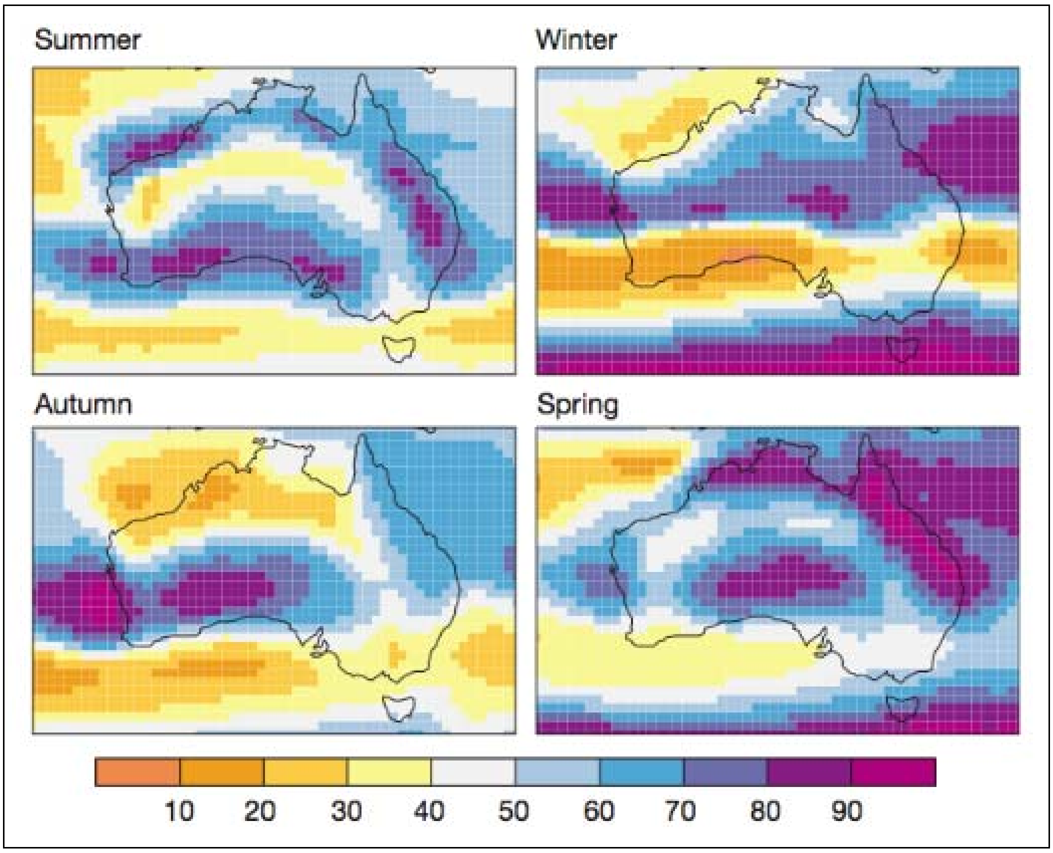

Figure 3.1. Probability (%) that seasonal wind speeds will increase by the year 2070 (CSIRO and BOM, 2007).

3.3 Projected Sea Level Rise

Sea level can be considered the ultimate controlling element in the geomorphology of coastal landforms (Bird, 1993; Hopley *et al.* 2007). There is consensus within the literature that low-lying islands, like those in the Torres Strait, are sensitive to the effects of sea level rise (Watson, 2001; Hay, 2002; Kench and Brander, 2006; Barry *et al.* 2007; Nicholls *et al.* 2007; Smithers *et al.* 2007; Woodroffe *et al.* 2007).

The sea level at any particular time is the sum of mean sea level, plus the state of the tide, plus wave set up, wave run up and responses to atmospheric pressure and near shore winds (Figure 3.2). Global average sea level has been rising over the past fifty years and this is expected to continue and perhaps accelerate in the future (IPCC, 2007). Different factors combine to cause the global mean sea level to rise. The ocean absorbs heat from the atmosphere, causing it to warm. As it warms, thermal expansion causes the water in the oceans to increase in volume (Church *et al.* 2008). Increased air temperature also causes glaciers and ice sheets to melt faster and release more water into the ocean.

The most recent IPCC report predicts sea level rise of between 0.18 m and 0.59 m by the end of this century, depending on the rate of emissions (Meehl *et al.* 2007). These models did not fully take into account the possible contribution from glaciers, ice caps and the Greenland Ice Sheet. The IPCC suggests that including these factors could add 0.1 m to 0.2 m to the upper bound of sea level rise predicted, therefore suggesting a range of predicted sea level rise between 18 cm and 79 cm by the year 2099 (Meehl *et al.* 2007). The IPCC also notes that larger rises – up to one metre – are possible however the understanding of the processes is too limited to predict their likelihood and provide an estimate of their effects (Figure 3.3). There are concerns in the literature that these rates may still be underestimates (e.g. Rahmstorf *et al.* 2007, Hansen, 2007).

Mean sea level does not rise uniformly around the globe due to numerous factors including climatic variations (e.g. El Niño-Southern Oscillation). To more accurately predict the amount of sea level rise likely to occur around Australia by 2070 the CSIRO and Antarctic Climate & Ecosystems Cooperative Research Centre (ACE CRC) projected the likely regional departures from the global average sea level (Figure 3.4). These regional projections suggest that around Torres Strait sea level rise is likely to be up to 25 mm greater than that predicted by the IPCC.

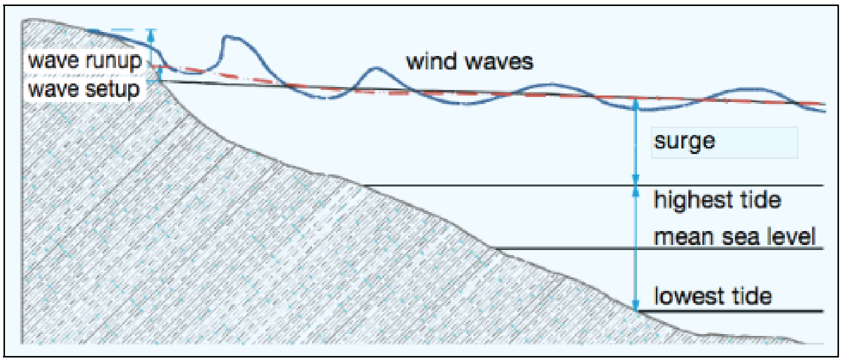

Figure 3.2. Contributors to coastal sea level from tides, surge and wave processes. Source: McInnes, 2007.

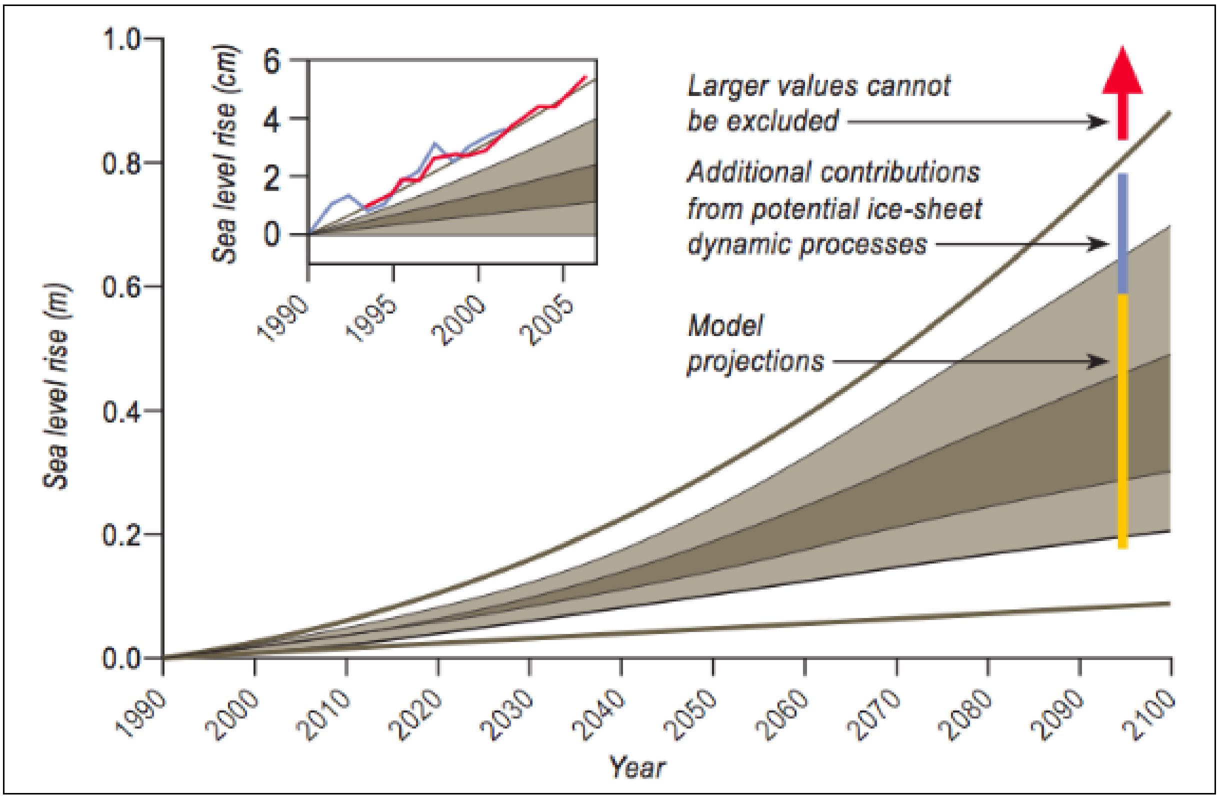

Figure 3.3. Projected sea level rise estimates up to the year 2100 (Meehl *et al.* 2007). Inlaid graph shows the observed global sea level rise measured by tide gauges (blue lines) and satellite altimetry (red line). Source: ACE CRC, 2008.

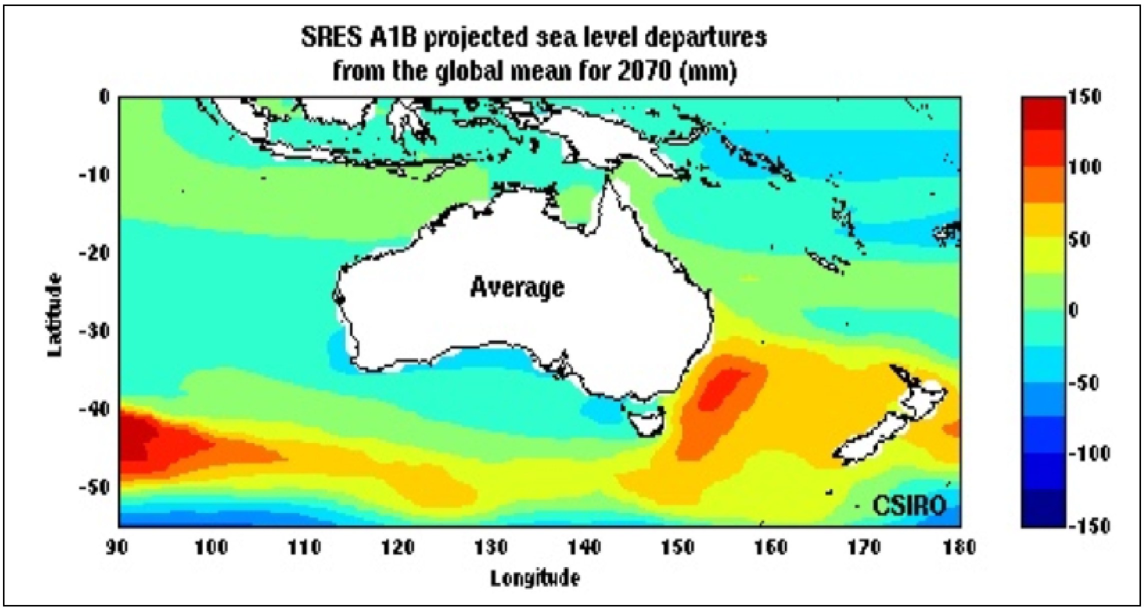

Figure 3.4. Sea level rise predicted around Australia for the year 2070 based on mid-range emission scenarios. Colours show the number of millimetres above (positive) or below (negative) the predictions of the IPCC that sea level is likely to rise in those areas based on an average 17 model runs. Source: http://www.cmar.csiro.au/sealevel/sl_proj_regional.html, 2010.

3.3.1 Sea Level Extremes

The greatest cause for concern in Torres Strait and other coastal communities is the combination of sea level rise and extreme events. Increased mean sea level will cause an increase in frequency of extreme sea level events (Department of Climate Change, 2009). The best available estimates suggest that mean sea level rise of 0.1 m by the year 2100 would double the frequency of high sea level, whereas a rise of 0.5 m by 2100 would increase them 1,000-fold in Cairns (the nearest station for which calculations have been performed) (Department of Climate Change, 2009). These show that the effects of rising sea level are not linear. Events which now happen every ten years could happen approximately every ten days in 2100.

3.4 Projected Sea Surface Temperature Rise and Ocean Acidification

The ocean absorbs approximately eighty percent of the heat added to the atmosphere (McInnes, 2007). Thus, ocean temperatures increase as global warming occurs. Global sea surface temperatures have been steadily warming over the past fifty years (Allison *et al.* 2009). Sea surface temperature in the Torres Strait is predicted to increase by between 0.4°C and 1°C by 2030 and between 0.6°C and 2°C by 2050 (Figure 3.5) (McInnes, 2007). Under high emissions scenarios warming of more than 3°C could occur by 2070 (McInnes, 2007).

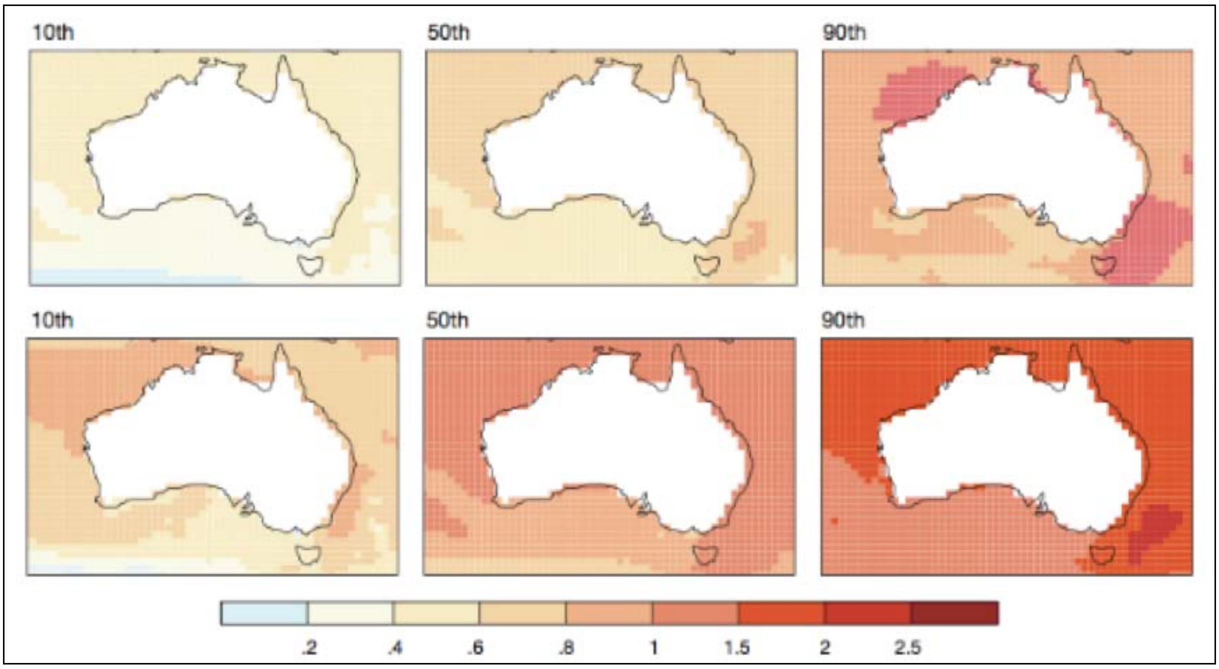

Figure 3.5. The 10th, 50th and 90th percentile values for projected annual change in sea surface temperature by the year 2030 (top row) and 2050 (bottom row) using the A1B emissions scenario proposed by the IPCC. A1B emissions scenario is characterised by rapid economic growth and rapid adoption of new efficient technologies (Nakicenovic and Swart, 2000). It can be considered a mid-range emission scenario. Source: Dunlop and Brown, 2008.

Carbon dioxide is one of the main gases produced by anthropogenic activities. The land and the ocean systems absorb carbon dioxide (CO_2) from the atmosphere. Increasing the concentration of CO_2 in the atmosphere leads to increasing acidification of the surface waters of the ocean as they absorb extra carbon dioxide from the atmosphere and create carbonic acid. The CO_2 content of the oceans increased by about 118 Gt (1Gt = 109 tons) between 1750 and 1994 and is continuing to increase by approximately 2 Gt each year (Allison *et al.* 2009). This has caused a decrease in surface ocean pH by an average of 0.1 units since 1750 (Allison *et al*. 2009). In the GBR geochemical records show that since the 1940s there is an overall trend of ocean acidification with pH decreasing by about 0.2-0.3 U (Wei *et al.* 2009). Figure 3.6 shows that at atmospheric CO_2 concentrations of 560 ppm, predicted to occur by approximately 2060 under standard emission scenarios used by the IPCC (Meehl *et al.* 2007), coral growth on the GBR and in Torres Strait will be between 20% and 40% of pre-industrial rates. This is projected to decline to between 0% and 20% by 2090.

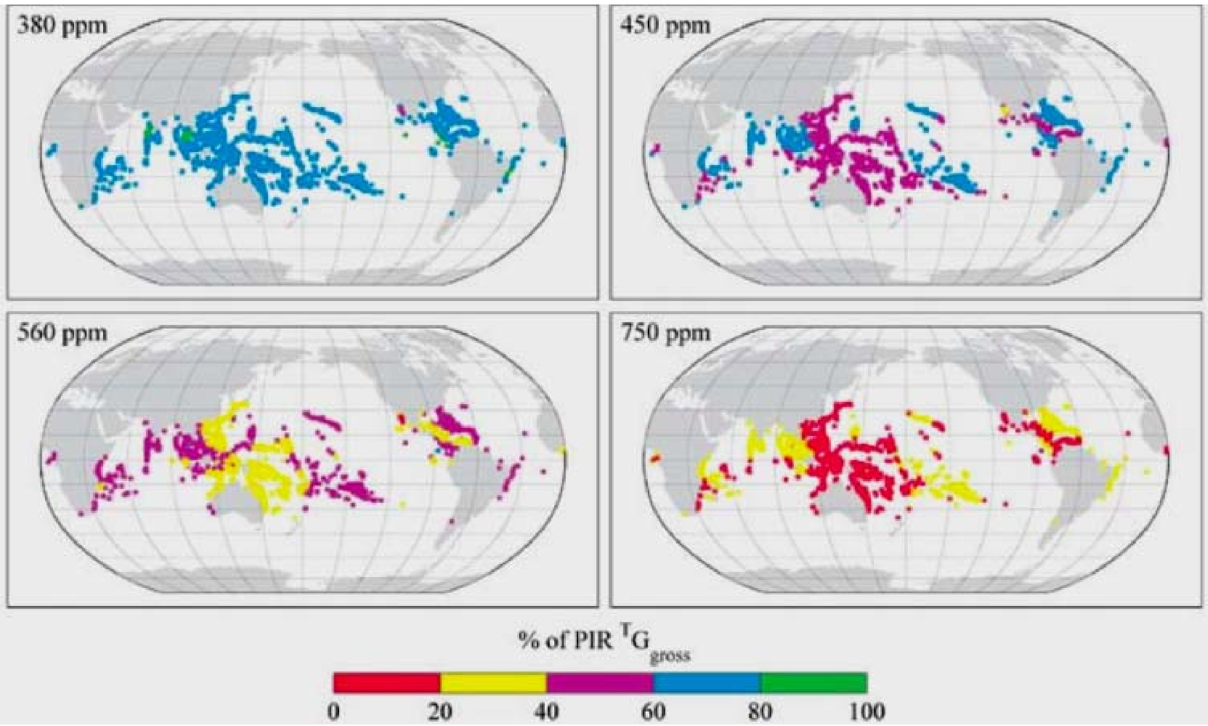

Figure 3.6. Calculated changes in reef building for coral reefs worldwide at four different atmospheric CO_2 concentration levels based on the predicted effects of changes in the pH and temperature of ocean waters on coral communities. The values are expressed as a percentage of pre-industrial gross calcification rates ($PIR^{T}G_{gross}$). Source: Klaypas and Yates, 2009.

There is evidence that climate change could be causing a decrease in dissolved oxygen concentrations in the global oceans (Allison *et al.* 2009). Lower oxygen causes respiratory issues for large predators and hinders the ability of marine organisms to cope with ocean acidification (Brewer, 2009). The phenomenon is modelled to affect oceanic zones between 200 m and 800 m in depth (Hofmann and Schellnhuber, 2009). However, it is not yet known how, or if, this would affect waters in the Torres Strait.

3.5 Latest Trends

Global observations of temperature, rainfall and extreme events since the IPCC report in 2007 have followed the projections and in some cases occurred faster than predicted (Allison *et al.* 2009). In fact, the global atmospheric warming trend has increased since 2006 from 0.177°C per decade to 0.187°C per decade (Allison *et al.* 2009). Summer-time melting of Arctic sea ice has far exceeded the worst case projections from the 2007 IPCC climate models (Allison *et al.* 2009). In turn, this suggests that sea level rise will also occur faster than predicted. Actual global sea level rise recorded between 1993 and 2008 has been 80% faster than was predicted by the IPCC in 2007 (Allison *et al.* 2009) (Figure 3.3). New estimates based on the observed relationship between global average temperature rise and sea level rise over the past 120 years suggest a sea level rise of around a metre or more by the year 2100 (Richardson *et al.* 2009). As it takes a long time for oceans and ice sheets to fully respond to a warmer climate, sea level will continue to rise for many centuries even after global temperature has stabilised (Allison *et al.* 2009).

4. Impacts of Climate Change in the Torres Strait

The projected changes in climate, sea level and sea surface temperature and chemistry will have vast physical and ecological impacts on the Torres Strait region. These impacts have severe economic, social and cultural implications for Torres Strait Communities will be exacerbated by the area's remoteness and other socio-economic factors (Briggs, 2010, Green, 2006, Green *et al.* 2010). Green *et al.* (2006) examined the likely impacts of climate change and sea level rise on *Ailan Kastom* (Island Custom). The Native Title Report 2008 included a case study on climate change and the human rights of Torres Strait Islanders highlighting the seriousness of the issue (Australian Human Rights Commission, 2008). The following describes just the physical and ecological impacts likely to be experienced in the Torres Strait.

4.1 Physical Impacts

The major physical impacts of sea level rise are inundation and increased coastal erosion (Department of Climate Change, 2009). These impacts are likely to be felt most acutely during extreme events (Green *et al.* 2010).

4.1.1 Inundation

Figure 4.1. Inundation experienced at Iama during king tides. Source: Iama Island Council.

The low elevation and small size of reef and mud islands in the Torres Strait makes inundation due to sea level a major concern (Wilkenson and Buddemeier, 1994, Mimura *et al.* 2007). Even on the high islands, many communities are concentrated around the low lying coastal fringe and are therefore also vulnerable. Inundation is defined as high water levels flowing from the surrounding sea and flooding low lying land (Woodroffe, 2008). Inundation during high tides and surge events is already a problem on some Torres Strait Islands. For example, in late January and late February 2006, the Torres Strait experienced storm tides 0.3 m higher than HAT. These tides were caused by king tides coinciding with a low pressure system and strong winds. They inundated low lying areas on many of the Torres Strait Islands and caused widespread concern for personal safety and infrastructure (EPA, 2006). Similar events are also known to have occurred in the 1940s. Sea level rise will increase the frequency with which land is inundated and perhaps eventually cause the permanent inundation of lowest areas.

4.1.2 Coastal Erosion

Figure 4.2. Beach erosion at the western end of Poruma.

Generally, sea level rise is expected to exacerbate coastal erosion by allowing more energetic waves to reach higher up the beach (Mimura *et al.* 2007). Coastal erosion is defined as a landward translation of the shoreline or loss of land to the sea (Komar, 2000), while accretion is a seaward translation of the shoreline (Dolan *et al.* 1991). Erosion presents serious problems in areas where coastal infrastructure and important cultural sites are threatened (Figure 4.2). A frequently applied principle, the Bruun Rule, suggests that sea level rise causes beaches to adjust their profile resulting in loss of land to the sea (Bruun, 1962). However, tropical coastal ecosystems are geomorphologically resilient and their response to environmental factors is often multidimensional and non-linear (Woodroffe, 2007). Reef islands (e.g. Warraber, Masig and Poruma), and high islands with significant fringing reefs (e.g. Iama, Thursday, Mer), may behave differently under higher sea levels. Many researchers, such as Hopley and Kinsey (1988) and Gourlay and Hacker (1996), argue that reef flats blanketed in sediment would be re-invigorated by sea level rise which would allow higher wave energy to transport the sediment towards the reef island facilitating the island's growth.

Increased sea levels could also increase the accommodation space for the reefs that are currently at sea level, allowing them to grow and produce more sediment (Woodroffe, 2008). Kench *et al.* (2003) also present an optimistic future for the reef islands of Torres Strait. Based on their conceptual model of reef island development (Kench *et al.* 2003) they suggest that islands would persist under current scenarios of sea level rise, although it is likely that changes in the shoreline orientation and perhaps island size would occur. Such changes in shoreline orientation could be equally damaging depending on the location of infrastructure.

As discussed above, the seasonal wind patterns in the Torres Strait play a strong role in determining water level, water circulation, and sediment transport through and around the Strait. A changed wind regime due to climate change would alter the wave regime experienced in the Torres Strait and thus change the shoreline processes and almost certainly island shape. Kench *et al.* (2009) suggest that the shape of the reef platform and island can provide an indication of how susceptible to shoreline change islands are likely to be. They found circular islands experience larger adjustments while elongated islands tended to be more stable (Kench *et al.* 2009).

4.2 Ecological Impacts

Climate change will also have substantial impacts on terrestrial and marine ecosystems and organisms in the Torres Strait.

4.2.1 Terrestrial Ecosystems

Increased mean sea level is expected to cause salt water intrusion into the islands' freshwater lenses or aquifers (Parry *et al.* 2007). This problem could be exacerbated by lower rainfall during the dry season and enhanced evapotranspiration. This could deplete supplies of potable water on the islands where it is used and could also damage terrestrial vegetation and ecosystems including vegetable gardens (Preston *et al.* 2006). However, work by Oberdorfer and Buddemeier (1986) showed that increased sea level may not necessarily result in decreased freshwater in the groundwater lens if the freshwater lens intersects the high-permeability Pleistocene reef sediments.

4.2.2 Marine Ecosystems

The health of marine ecosystems such as coral reefs and seagrass beds will be affected by increased water level, temperature and acidity. Debate surrounds how modern reefs will respond to sea level rise. The response of coral reefs to sea level rise in the past has varied largely depending on the rate of rise. Corals require sunlight to photosynthesise and survive. Therefore, they must grow within the euphotic zone where sufficient sunlight penetrates the water. When the sea level rises, so does the euphotic zone. Reefs respond by 'keeping up' or 'catching up' with the euphotic zone and growing upwards, or they 'give up' and are left behind (Hopley *et al.* 2007). Reefs will be left behind if the rate of sea level rise is too rapid and if they are not healthy and able to grow upward efficiently. It is likely that healthy reefs could keep pace with the rates of sea level rise predicted by the IPCC. However, other anthropogenic and climate change induced stresses, such as increases in water temperature and acidity, may limit the ability of reefs to keep pace with sea level rise (Veron *et al.* 2009).

Increasing sea surface temperature (SST) negatively affects corals. Zooxanthellae are single celled algae which live inside the tissue of corals giving them their colour and photosynthesising to supply the corals with energy. Coral bleaching occurs when the coral expels the zooxanthellae and begins to starve (Hoegh-Guldberg, 1999). Bleaching is a stress response triggered by high sea surface temperatures, over-exposure to sunlight (ultraviolet radiation), disease, pollution or low water salinity or any combination of these factors. If conditions return to normal corals can regain their zooxanthellae and survive. However, severe bleaching results in the death of corals. Coral reefs may take years or decades to recover from a bleaching event (GBRMPA, 2010). Increasing sea surface temperatures and ocean chemistry changes brought about by climate change are likely to result in more frequent and severe bleaching events (Department of Climate Change, 2009).

In late February or early March 2010 a substantial bleaching event occurred in Torres Strait (Figure 4.1). The bleaching was observed on the reef surrounding Thursday Island and affected colonies of most species particularly staghorn (*Acropora*) and soft corals (TSRA, 2010). This is the first bleaching event recorded in the region and is thought to have been caused by warmer than normal water temperatures combined with low tides (TSRA, 2010). Satellite records show that heat stress was accumulating throughout February and SSTs were 3°C greater than the regional long-term average by 15 March. In addition to this heat stress, low tides occurred during the mid afternoon in March, exposing corals to high levels of ultraviolet radiation.

Increased water temperatures are also predicted to decrease the productivity of seagrasses, particularly those in shallow or intertidal waters (Waycott *et al.* 2007). Seagrasses are dependent upon the ability of light to penetrate the water, allowing them to photosynthesise. Sea level rise is likely to reduce the amount of light available to seagrasses, particularly those in deep water, and thus decrease the amount of viable habitat available to them (Waycott *et al.* 2007). Seagrasses may be able to colonise new areas inundated by sea level rise. However, this is dependent on numerous factors including the substrate. Coastal developments creating hard surfaces, such as concrete, at the shoreline will limit the ability of seagrasses to colonise (Waycott *et al.* 2007). Changes in the wind direction could also cause sandwaves present on the seabed to migrate differently covering seagrass fields (Heap *et al.* 2005).

Ocean acidification is expected to cause a reduction in coral and coralline algae growth and reduce the ability of corals and other marine organisms to produce skeletons and shells. This will have negative affects on reef ecosystems (Veron *et al.* 2009). It may negate any positive impacts on sediment production provided by increased reef accommodation space due to sea level rise. However, Kleypas and Yates (2009) suggest that ocean acidification could benefit seagrasses. This may have a positive effect on dugong populations in the Torres Strait. Dugongs are a culturally important species to Torres Strait Islanders (Green *et al.* 2010). However, the biological and ecological effects are complex and, as yet, poorly understood (Kleypas and Yates, 2009).

Increased wet season rainfall is likely to increase the amount of sediment discharged into Torres Strait by terrestrial rivers, particularly those in PNG. Increased sediment in the water can smother corals and restrict the growth of seagrass by limiting the amount of sunlight that reaches them (Hemer *et al.* 2004). A decline in seagrasses could harm dugong populations. Increased water turbidity has also been noted to negatively affect sponge growth (Duckworth *et al.* 2009). This has negative implications for the commercial sponge industry in Torres Strait as well as for general coral reef health.

Given the complex and close links between islands and coral reefs in the Torres Strait the ecological impacts of climate change on reef ecology have physical implications for the islands. Reefs provide a buffer zone causing waves to break offshore and thus reducing the energy of the waves when they reach the shore and protecting the beach from erosion. If sea level rises and reefs are not able to 'keep up' this protective buffer may be lost and more energy will reach shorelines exacerbating erosion problems (Department of Climate Change, 2009).

Shifts in reef top ecology and associated changes in carbonate production, such as those likely to be brought about by climate change, have major implications for sediment reservoirs and the development and maintenance of island beaches (Hart and Kench, 2007). Much of the sand on island beaches in the Torres Strait (except mud islands like Boigu and Saibai) is carbonate and is produced on the surrounding reef flat or fringing reef (Hart and Kench, 2007). This is particularly true of the cay islands (e.g. Warraber, Poruma and Masig) where the islands are made exclusively from sediment provided by the reef flat. Thus, a decline in the health and growth of coral and other carbonate producing organisms could limit the amount of sediments available to the beach and perhaps increase beach erosion.

At least initially however, sediment production of reefs may increase as wave energy increases due to sea level rise and thus more reef flat sediment is able to be transported to island beaches. In addition, as coral skeletons created under acidified conditions are likely to be weaker they will be more prone to breakage during high-energy conditions and may contribute substantial amounts of rubble to the sediment budget (Veron *et al.* 2009). A bleaching event may temporarily increase sediment availability, but the decline in reef health and productivity is, in the longer term, likely to be detrimental.

Deterioration of coral reef health and productivity is likely to cause declines in other marine species such as crustaceans, including crayfish, which are the basis of an important industry in Torres Strait, and reef fish. However, these effects are not well understood and require further study (Kleypas and Yates, 2009). Climate change is also expected to impact tropical animals such as turtles and crocodiles whose breeding is affected by seasonal weather conditions (Dunlop and Brown, 2008).

Sea turtles are an important cultural food source for Torres Strait communities and are also an important part of tropical marine ecosystems (Fuentes *et al.* 2010a). Temperature increases are likely to impact sea turtles which are dependent on temperature for the sex determination and hatching success of young (Fuentes *et al.* 2010b). Warmer sand temperatures produce predominantly female eggs. Fuentes *et al.* (2010a) modelled the probable effects of climate change on turtle hatchlings in the northern Great Barrier Reef. They found that by the year 2070 almost all hatchlings will be female although some sites will still produce male hatchlings. There is also concern that turtle nesting areas (rookeries) will be eroded or inundated due to sea level rise and that flooding by wave run-up during storms will increase egg mortality (Fuentes *et al.* 2010a). Thus, further decline in turtle numbers in the Torres Strait is likely. Some communities have already experienced unprecedented difficulty catching turtles (Green *et al.* 2010).

Figure 4.3. Bleached coral on the reef flat surrounding Thursday Island following a bleaching event in February or March of 2010. Source: Torres Strait Regional Authority.

5. Adaptation and Mitigation Measures

As shown in Figure 5.1, global and local causes of change on small islands are likely to increase for the rest of this century, and without adaptation measures these changes will result in sharp declines in island condition and well-being (Parry *et al.* 2007). To offset the negative impacts and improve island condition by the year 2100, adaptation strategies must be implemented immediately. This requires a holistic, multi-jurisdictional approach with strong community involvement.

Small Island communities have adapted to variability in climate and sea conditions and extreme events over a long period of time (Parry *et al.* 2007). Torres Strait Islanders, whose ancestors are believed to have migrated from the Indonesian archipelago some 70,000 years ago when the islands were still connected to the mainland (ABC/Cinemedia, 2005), are no exception, with stories of adaptation punctuating their history even within living memory (Green *et al.* 2010). Traditional knowledge and past experience is valuable in dealing with the changes likely to be associated with climate change and can strengthen the adaptive capacity (Parry *et al.* 2007). However, in many small island communities, both in the Torres Strait and worldwide, mobility and other traditional mechanisms to cope with environmental hazards have been lost or diminished (Parry *et al.* 2007). This is partially due to the development of hard infrastructure which cannot easily be moved.

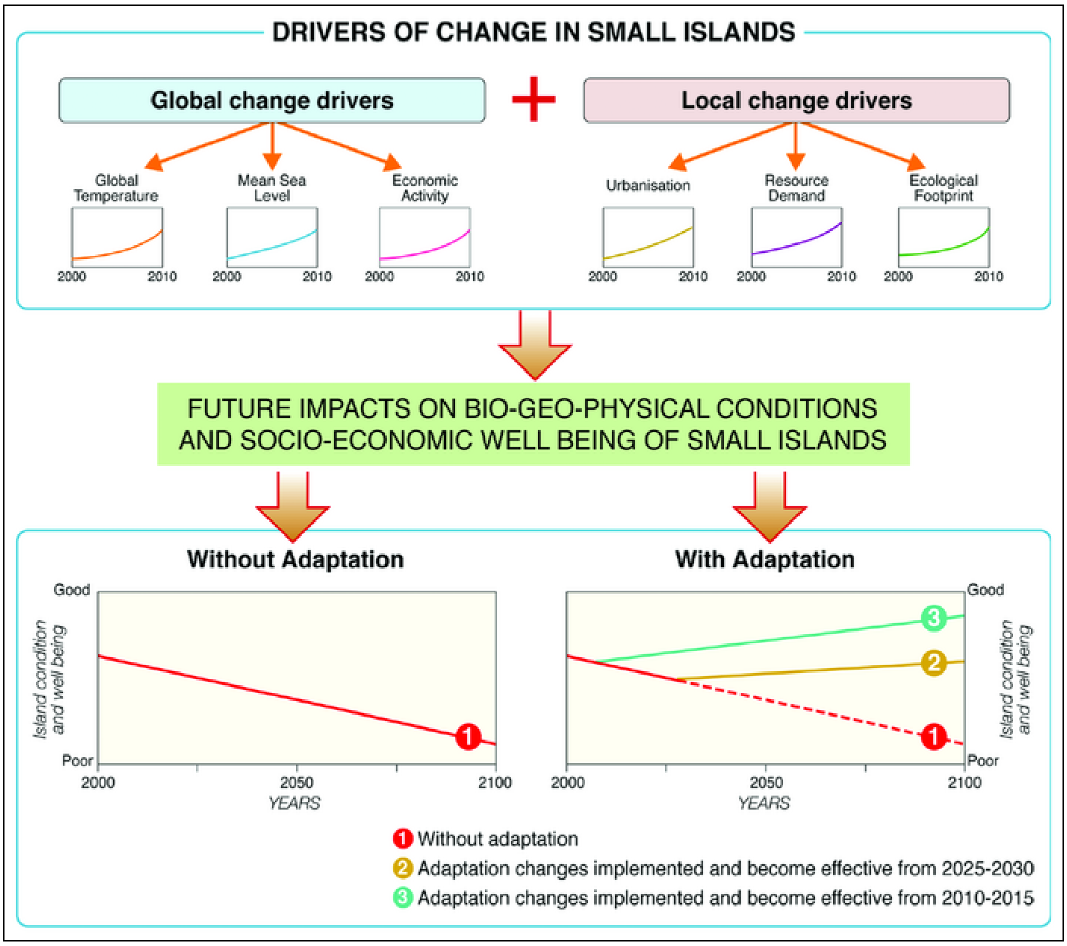

Figure 5.1. Drivers of change in small islands, and the implications for island condition and well being under 'no adaptation' and near-term and mid-term implementation of adapation. Source: Parry *et al.* 2007.

To date many coastal adaptation measures have been reactive. Proactive adaptation strategies can offer co-benefits including energy security, water security and environmental protection (Parry *et al.* 2007). Ensuring viable freshwater on all islands is a key adaptation measure. Many islands in Torres Strait have desalination plants and so are no longer dependent on freshwater occurring naturally on the island for their drinking supplies. Rainwater tanks should also be considered as a positive and sustainable initiative.

In relation to the most obvious projected effects of climate change (sea level rise causing erosion and inundation), coastal protection works (hard structures) are frequently suggested. These are expensive and need to be evaluated on a case by case basis in terms of their benefits and unwanted consequences, against other soft options and other mechanisms such as relocation of infrastructure or retreat.

Soft adaptation activities that could be undertaken to mitigate the effects of inundation and coastal erosion include beach and mangrove revegetation, maintenance of the supratidal berm and beach renourishment. The berm is a feature which forms a rim around most coral cay islands and can often be found at the top of the beach on high island shorelines. It presents a barrier and will assist in preventing or slowing the passage of water inland even if the level of the land behind it is lower. Although the water can penetrate through the sediments, the period of the high tide is short and the water does not have time to fully inundate low lying areas landward of the berm.

Renourishment is the addition of sediment transported from elsewhere to the eroding beach system. To ensure successful renourishment the type of sediment used and its grain size and settling properties must be considered. It is best to use sediment which is coarser and more poorly sorted than that which naturally occurs to ensure stability and reduce scour of the beach (Kirk, 1993). Renourishment is not a ‘once off’ solution and would need to be repeated annually to ensure success. Although renourishment is often seen as a good alternative, finding a source of suitable sediment is frequently problematic.

On many of the Torres Strait islands vulnerability to inundation and coastal erosion is increased because of the location of infrastructure in areas very close to the shoreline. Retreating from the shoreline is an adaptation option which should be considered. However, this is not possible on some islands (e.g. Poruma) due to land space limitations, or a lack of high land (e.g. Boigu and Saibai). For islands where this is not a problem (e.g. Iama and Mer), the available land is often too steep and complex traditional land ownership issues may arise (Green *et al.* 2010).

More complex adaptation options include the installation of seawalls, groynes or offshore breakwaters. Decisions surrounding any of these options should be informed and planned using a morphodynamic approach that considers the complex interactions and processes occurring on the island and reef and the consequences that any adaptation options are likely to have (Woodroffe, 2008). Sea walls are hard, parallel-to-shore structures usually built to manage erosion or inundation threats to a developed coastline. They are poor dissipaters of wave energy, causing wave reflection and run up which often overtops the structure (Walker and Cox, 1999). They have the effect of degrading the high tide beach directly in front of them and often for some distance down coast (Kraus, 1988; Pilkey and Wright, 1988). The removal of the high tide beach increases the coastline’s vulnerability to wave action and can exacerbate the damage caused by flooding during high energy periods. In addition, by fixing the shoreline, sea walls inhibit the natural ability of reef islands to grow and evolve in response to changed conditions and therefore remove much of their resilience to change (Asher, 1994). Sea walls are also prone to flanking, the process by which wave energy attacks the ends of a sea wall exacerbating erosion of the shoreline both behind and adjacent to the wall (Kraus and McDougal, 1996).

Groynes are structures of varying size and design, erected perpendicular to the shore, which are usually constructed for coastal protection and, when successful, can maintain beach width and prevent sediment from escaping alongshore (Hanson and Larson, 2004). However, these structures impede natural sediment transport pathways and often relocate erosion problems down-drift (Gillie, 1997, White and Healy, 2000, Schoonees *et al.* 2006). Alongshore transport is fundamental to the morphological stability of islands (Cowell and Kench, 2001; Kench *et al*. 2003). Cowell and Kench (2001) suggest that, in terms of littoral transport, interruptions such as groynes could have greater impacts on shoreline morphology than sea level rise. Other shore-perpendicular structures such as jetties and boat ramps can also act as groynes.

Gabions are other parallel-to-shore structures that act as energy dissipaters and encourage the accumulation of sand. They are seen as 'softer' engineering methods. Gabions have several advantages over the structures outlined above (Ragoonaden, 1997). Because they dissipate energy and are able to resist wave and current damage they are more durable. They can also be dismantled relatively easily and relocated in response to changes in the local environment. Gabion structures are usually cost effective and can also facilitate plant growth as voids become filled with sediment. This means that they can adapt and evolve with the shoreline and do not preclude island growth and shoreline change (Ragoonaden, 1997).

Offshore breakwaters are designed to dissipate wave energy before it reaches the shoreline and therefore limit the amount of erosion experienced. Coastal protection units (CPUs) are one type of offshore breakwater designed to accumulate sediment on their landward side. They are slated concrete blocks placed in a line broadly parallel to the shore which act similar to a breakwater (Kirk, 1993). They protect the shore by allowing sediment to pass through whilst dissipating wave energy. As the structures are permeable they do not create a complete barrier to longshore sediment transport as groynes do and so are less likely to have negative impacts alongshore (Kirk, 1993). CPUs have several other advantages over traditional hard mitigation measures. They are able to be constructed relatively easily with material readily available on most reef islands and can be installed using an ordinary tractor (Kirk, 1993). CPUs can also be removed when they are no longer needed and relocated to new sites as required. They are more efficient than sea walls or groynes at dissipating energy and thus cause less reflection and overtopping (Walker and Cox, 1999). They are a relatively new technology, but have been used with some success in the Cook Islands. However, some feel they detract from the aesthetic value of the beach (Swick, 2006).

While most of the above mentioned adaptation measures need to be considered on a case by case basis, some principles can be applied to all islands. Predicting the areas likely to be affected by inundation and erosion allows managers to focus their mitigation activities. Protecting the natural supratidal berm of the beach is important to minimise the risk of inundation during high tides under raised sea level conditions. Anthropogenic stresses on reef ecosystems, such as water pollution, over fishing and coral damage, decrease the resilience of corals and seagrasses (Veron *et al.* 2009). Limiting these impacts and maintaining healthy reefs will improve the chances of reefs to survive and adapt naturally to the conditions brought about by climate change (Waycott *et al.* 2007).

To mitigate the effects of warmer incubating temperatures on sea turtles, Fuentes *et al.* (2010a) suggest that turtle nesting grounds (rookeries) which are capable of producing male hatchlings should be identified and protected. Other methods such as modifying sand temperature by artificial shading, vegetation cover and sprinkling of cool water are also suggested to ensure that sand temperature stays within the optimal temperature range. Relocating nests is another option, as well as focusing cultural egg harvesting in areas where the sand is too warm to produce successful hatchlings (Fuentes *et al.* 2010a).

Changing the basic driving mechanisms of climate change at a local or regional level is virtually impossible and therefore adaptation to new conditions is the only realistic way forward. Examples of adaptation to changes in some of the basic climatic conditions include not building new buildings in areas that may be flooded by sea level rise of up to one metre, planning new developments on the highest parts of the island, and discussing land ownership issues which may arise from this as early as possible.

5.1 Land Use Planning

Adaptation and mitigation of climate change in the Torres Strait has become a key priority. A Torres Strait Climate Change Strategy is being developed by the Torres Strait Regional Authority, working together with different government agencies and research organisations. In the past, the development and growth of Torres Strait island communities has proceeded in a somewhat ad hoc manner resulting in the inappropriate location of houses and infrastructure and haphazard provision of services (Doust, 2009). Sustainable land use planning helps Island Councils to understand the impacts of development on the natural environment and manage the islands sustainably into the future. Sustainable land use plans (SLUPs) document and take into account the:

- Environmental assets of each island;
- Land use issues, including development along the coast and in erosion prone areas, land tenure, potential acid sulfate soils and increasing tide and surge levels;
- Infrastructure issues;
- Strategic location issues;
- Population issues;
- Growth issues; and
- Housing issues.

Sustainable land use plans have been developed by CONICS for Boigu, Dauan, Saibai, Masig, Iama and Erub. Plans are currently in development for Hammond, Kubin, St. Pauls, Badu, Mabuiag, Warraber, Poruma, Ugar and Mer. On each island the SLUPs adhere to the ‘best practice’ guidelines respecting the natural dynamic processes that shape the coast and beaches (Doust, 2009). They commit to the strategic outcome that land adjoining the coast should be free from development to avoid the dynamism and natural hazards associated with coasts and beaches.

The SLUPs recognise the importance of climate change and aim to reduce its impacts by avoiding quick decisions that will make the management of climate change risks more difficult in the future and by building understanding and capacity of the communities to deal with climate change impacts (Doust, 2009). The plans adopt a possible increase in sea level rise of 0.59 m by the year 2100 based on IPCC predictions (Meehl *et al.* 2007) and recommend that this number be reviewed at least every ten years. The plans calculate how many days of the year the predicted high tides will inundate each island or overtop sea walls, then calculates the number of days this would happen if a sea level rise of 0.59 m was to occur and the areas which would be affected. Future development is not permitted within these areas. To mitigate the impacts of future sea level rise and surge, the plan recommends that existing houses be modified and new houses be constructed to include a ‘refuge area’. These areas are designed to withstand possible surge and tidal inundation during extreme events (Doust, 2009). It is also recommended that house designs include a ‘strengthened area’, i.e. bathroom/laundry and an upper living area floor at least 4.9 m LAT. The plans also advise that mechanical and electrical works are located above predicted year 2100 HAT.

6. Progress and Knowledge Gaps

Determining an accurate and reliable tidal datum for the Torres Strait is an urgent challenge. Creating sustainable land use plans that adhere to the best practice principles outlined above requires accurate knowledge of land elevation and tidal levels, particularly the predicted level of high and surge tide events for each island. Therefore, establishing a suitable tidal datum is of the utmost importance. The Australian Government recently announced $1 million funding for tide gauges to monitor the sea level on at least four islands. There is a possibility that Geoscience Australia will update its *AusGeoid* model for North Queensland and Torres Strait based on tidal data collected in the area by this and other projects. This should increase the accuracy of tidal predictions in the region and help develop a reliable tidal datum.

Surge events that increase mean water levels for periods of time must also be understood if an adequate tidal datum is to be established. Currently a probabilistic assessment of extreme ocean water levels and inundation hazard in the Torres Strait is underway. This study will model mean surface water level for the period of tidal data collection and, taking wind into account, create an island by island tidal correction. Tropical cyclone simulation modelling will then be undertaken. LIDAR (light detection and ranging) imaging has been conducted on behalf of the TSRA on Saibai and Boigu islands, providing detailed digital elevation models of this area to help in modelling the affects of sea level rise and surge. Similar imaging is planned for the remaining islands. More detailed knowledge of the bathymetry of Torres Strait is also needed to facilitate reliable surge modelling (Green *et al.* 2010).

The coastal dynamics of each island in the Torres Strait is unique to the island and many factors govern how each island responds to predicted changes in climate. A comprehensive understanding of island dynamics is fundamental to accurately predicting the impacts of climate change and facilitating effective adaptation and mitigation activities. Without a good understanding of island processes there is a risk that adaptation and mitigation measures could exacerbate problems like coastal erosion. Further research predicting the likely consequences of hard engineered mitigation measures on islands is also needed. The Australian Government has announced $400,000 funding for new research into the impacts of climate change including inundation and coastal erosion on Torres Strait communities (media release dated 5 May 2010[1]).

The biophysical response of coral reef flats and fringing reefs in the Torres Strait to the combined effects of sea level rise, sea surface temperature rise and increased ocean acidity must be understood. It is essential to properly predict reef responses to these factors and the implications this will have for islands and communities. While the process of coral bleaching is well documented in the GBR and elsewhere the process and critical thresholds for corals in the Torres Strait is almost entirely unknown. The causes of recent coral bleaching and monitoring of recovery are important to predict and mitigate these events in the future. At present little is known about how reefs worldwide will respond to higher ocean acidity let alone how to mitigate the impacts of this.

Global climate models provide good insight into the general type and possible magnitude of climate changes to be expected. However, changes vary spatially due to numerous local and regional factors. For this reason regional climate models are necessary. The CSIRO is presently reviewing regional climate models for the Torres Strait area as part of a larger Papua New Guinea/Asia Pacific project. Detailed and long-term observations are required in order to produce reliable regional climate models for the area. Little long-term and reliable data regarding climatic and sea level conditions are available at present. Given the variability

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[1] 'Assisting Torres Strait Communities with the Impacts of Climate Change', joint press release issued 5 May 2010 by Senator the Hon. Penny Wong, The Hon. Jenny Macklin MP and Mr Jim Turnour.

in conditions within Torres Strait, these data need to be collected at numerous locations throughout the region. There remains considerable uncertainty globally regarding the effects of climate change on key processes such as wind regimes and cyclones, and how these can be modelled. Work needs to continue in this area to ensure communities are prepared and able to adapt effectively.

7. Discussion and Conclusion

The Torres Strait is a dynamic, diverse and significant region geomorphologically, ecologically and culturally. Its physical and ecological environments are sensitive to the affects of predicted climate change. These changes and their impacts are already of considerable concern to Torres Strait island communities. A proactive and holistic approach to planning and management is required to ensure successful and sustainable adaptation and mitigation measures are adopted and the islands remain habitable and in good condition into the future.

While the exact nature and rates of climate change remain uncertain, there is general consensus around a number of variables (at a broad scale) and less certain regional scale projections. Debate will continue for some time as to the reliability of estimates at both global and regional scales, but prudent planning requires that some estimates relating to basic variables are adopted. Although it has been suggested that rates of change in many variables are tracking at or above the upper limits (Allison *et al.* 2009), at this stage, and based on the available literature, the following projections are appropriate to use for adaptation planning for Torres Strait:

- 1-4°C temperature increase by 2070;
- 10% increase in downwards radiation by 2070;
- 0.8-13.2% increase in wet season rainfall by 2070;
- 3.9-23% decrease in dry season rainfall by 2070;
- 16% increase in evapotranspiration by 2070;
- 2-5% increase in wind speed by 2030 and uncertain changes to wind direction;
- Sea level rise of up to one metre;
- Up to 3°C increase in sea surface temperature by 2070; and
- Decreased ocean pH.

These changes will have an array of physical and ecological impacts which will have great social and cultural mplications. The exact response will differ from island to island and in many cases there is great uncertainty. Physical impacts include increased inundation of land and increased frequency and severity of surge events. Coastal erosion (or change in shoreline orientation) may also increase; however, as discussed in Section 4.1.2, some Torres Strait islands could be quite resilient to this dynamism. This is dependent on coral reef health, the geomorphic process regime, and the location of existing island infrastructure. Increased bleaching events and decreased rates of coral growth and sediment production are likely to have flow-on effects on other species in the ecosystem as well as implications for island sediment budgets.

There are numerous adaptation and mitigation measures, including hard and soft engineered works, which can minimise the negative effects of climate change and even improve island condition. These must be considered on an island by island basis to ensure they are successful and negative consequences resulting from them are understood, minimised and acceptable to communities. Adaptation needs to start early, and this requires plans to be in place urgently. All agencies must cooperate with the communities to ensure outcomes that will be sustainable into the future, and expedient, but unsustainable projects must be avoided.

Though the impacts of climate change in the Torres Strait are likely to be significant, appropriate and well thought-out adaptation and mitigation measures will help to make communities sustainable into the future.

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