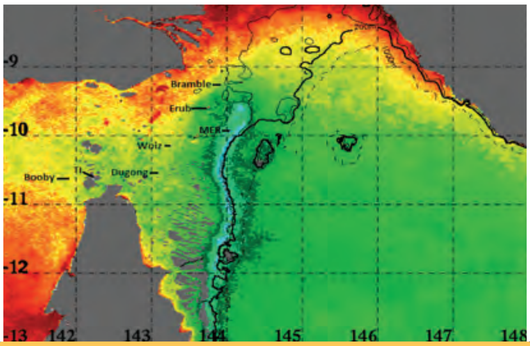
National Environmental Research Program

TROPICAL ECOSYSTEMS hub

Final Report

Monitoring the Health of Torres Strait Reefs



Scott Bainbridge, Ray Berkelmans,
Hugh Sweatman and Scarla Weeks

Australian Government
Department of the Environment

Reef & Rainforest RESEARCH CENTRE

Monitoring the Health of Torres Strait Reef

Final Report

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Australian Government

AUSTRALIAN INSTITUTE OF MARINE SCIENCE

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

Australian Government

Department of the Environment

Supported by the Australian Government's
National Environmental Research Program

Project 2.3 Monitoring the health of Torres Strait coral reefs

National Library of Australia Cataloguing-in-Publication entry:

978-1-925088-65-6

This report should be cited as:
Bainbridge, S.J., Berkelmans, R., Sweatman, H and Weeks, S. (2015) *Monitoring the health of Torres Strait Reefs – Final Report*. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (pp.74).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Research Program (NERP) Tropical Ecosystems (TE) Hub.

The Tropical Ecosystems Hub is part of the Australian Government's National Environmental Research Program. The NERP TE Hub is administered in North Queensland by the Reef and Rainforest Research Centre Limited (RRRC). The NERP Tropical Ecosystems Hub addresses issues of concern for the management, conservation and sustainable use of the World Heritage listed Great Barrier Reef (GBR) and its catchments, tropical rainforests including the Wet Tropics World Heritage Area (WTWHA), and the terrestrial and marine assets underpinning resilient communities in the Torres Strait, through the generation and transfer of world-class research and shared knowledge.

Cover photographs: (Anti-clockwise from top) Training of LSMU Sea Rangers in the Manta Tow method (source: AIMS LTMP Team), Masig Island ocean monitoring station (source: Scott Bainbridge), Remote Sensing Sea Surface Temperature Map (source: Scarla Weeks, data from NOAA), Deployed Temperature Logger (source: Ray Berkelmans).

This report is available for download from the NERP Tropical Ecosystems Hub website:
http://www.nerptropical.edu.au/research

January 2015

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Acronyms Used In This Report

AIMS............. Australian Institute of Marine Science
AMSA .... Australian Maritime Safety Authority
CMAR............ CSIRO Division of Marine and Atmospheric Research
COTS............. Crown of Thorns Starfish
CSIRO............ Commonwealth Scientific and Industrial Research Organisation
DoE .... Department of the Environment
ENSO............. El Niño Southern Oscillation
GBR............... Great Barrier Reef
GBRMP……... Great Barrier Reef Marine Park
GBRMPA....... Great Barrier Reef Marine Park Authority
IMOS............. Integrated Marine Observing System
JCU................ James Cook University
LSMU .... The Land and Sea Management Unit of the TSRA
LTMP............. Long-term Monitoring Program
MODIS .... Moderate Resolution Imaging Spectro-radiometer
MSQ.............. Maritime Safety Queensland
MTQ.............. Museum of Tropical Queensland
NCEP .... National Centers for Environmental Prediction
NERP .... National Environmental Research Program
NOAA .... US National Ocean and Atmospheric Administration
OBIS ……… .. Ocean Biodiversity Information System
OISST .... Optimum Interpolation (OI) Sea Surface Temperature
PNG............... Papua and New Guinea
POAMA......... Predictive Ocean Atmosphere Model for Australia
QPWS............ Queensland Parks and Wildlife Services
RHIS .... Reef Health and Impact Surveys
RRRC............. Reef and Rainforest Research Centre Limited
SST................ Sea Surface Temperature
TI................... Thursday Island
TS.................. Torres Strait
TSRA .... Torres Strait Regional Authority
UQ .... The University of Queensland

Abbreviations Used In This Report

Fig................. Figure
Is .... Island
Rf .... Reef

Acknowledgements

The project recognizes, acknowledges and thanks the traditional owners of the areas visited; without the support of the local communities this project would not have been possible. To the island communities of Poruma, Masig, Erub and Mer, and their traditional owners, the Porumalgal, Masigalgal, Erubam Le and Meriam Le, for allowing us to survey reefs and place equipment in their sea country, Esso.

Esso (thanks) to staff of the Torres Strait Regional Authority Land and Sea Management Unit, particularly Stan Lui, Ron Fujii, Frank Loban, Tristan Simpson and Troy Stow for their advice and assistance in organising the fieldwork; all the TSRA Torres Strait Rangers that participated in the training and field work: Ranger Supervisor Troy Stow, Warraberalgal: Laura Pearson, Mark Pearson, Aken Baragud; Porumalgal: Joseph Desmond David, Kevin Levi; Iamagal: David Baragud; Erubam: Aaron Ketchell, Amos Sipi; Boigu: Nelson Biguma, Keiji Bowie, Frank Nona.

Thanks also to Damien Miley and Vic McGrath of the TSRA for their invaluable support and help that was very much appreciated.

Thanks to Paul Muir for his help with coral taxonomy, and to Fiona Merida, Emily Smart and Jeremy Goldberg for assistance with RHIS training at short notice. Thanks to the AIMS crew of Scott Gardner, Shaun Hahn and Ray Boyes for their untiring help. Thanks also to Marcus Oke and the crew of the MV Floreat and Shane Steele and the crew of the MV Elizabeth E II for their help.

The project recognizes the valuable input from the RRRC and C_2O staff, especially Johanna Johnson, and the support of Damien Wrigley from the Department of the Environment along with the other staff from the Department.

The project was funded through co-investment with the Tropical Ecosystems Hub of the Australian Government's National Environmental Research Program.

Executive Summary

This project: *Monitoring the Health of Torres Strait Reefs* under the National Environmental Research Program (NERP) Tropical Ecosystems (TE) Hub, documented the current state of representative reefs of the Torres Strait. It also measured and monitored key ocean parameters to identify spatial and temporal patterns of temperature and other stresses that may impact the reefs of the Torres Strait region.

The reefs of the Torres Strait have not been studied in detail and so there is an information gap in relation to what species are present on the reefs and what condition they are in. This is in contrast to the reefs of the Great Barrier Reef World Heritage Area, which have been extensively studied with a documented 30% decline in coral cover over the last 27 years. Extensive coral bleaching was observed in the Torres Strait in 2010 for the first time indicating that the reefs in this region are potentially under many of the same stresses as reefs to the south. Documenting the current condition of the reefs and understanding the large-scale environmental drivers that can impact reefs is critical in maintaining and preserving the reefs of the Torres Strait.

The project has four main components. The first involves reef surveys to measure and document the biodiversity and status of key representative reefs in the Torres Strait. The other three components provide information about current environmental conditions and potential stressors such as high sea temperatures. Together they provide a measure of the current state of reefs and current environmental stressors, in particular temperature, on these reefs. The project therefore looks to provide a measure of the health of the reef systems.

The project has achieved the following:

- Undertaken two biodiversity reef surveys with a focus on the central and eastern reefs that have resulted in the discovery of new coral and fish species in the region.
- Developed local capacity and expertise in reef survey methods, logger deployments and first-level ocean monitoring station diagnostics with the LSMU Sea Rangers and other LSMU staff that has resulted in a strong foundation to continue the work into the future.
- Deployed and exchanged a series of temperature loggers at 14 sites around the Torres Strait, and developed bleaching thresholds for Thursday Island as part of a longer-term temperature record for the Torres Strait against which future conditions can be assessed.
- Deployed three real-time ocean monitoring stations linked into coral bleaching models and alerting systems, the above water weather data is available via data kiosks on Thursday and Masig Islands as well as the local radio station.
- Developed long-term monthly average satellite-derived sea temperatures against which current satellite images can be compared to show areas that are warmer and cooler than the long-term average. These anomaly maps have been produced monthly so potential areas of thermal stress can be identified to supplement the real-time stations in predicting future bleaching risk.
- Developed a draft coral reef monitoring plan (see Appendix 1) that utilises and builds in regional capacity and resources as a framework for continued monitoring of the health of Torres Strait reefs.

Key outcomes and knowledge from NERP project 2.3 include:

- Reef surveys documented 245 species of coral, of which an estimated 77 are new records for the Torres Strait with some species being potentially new records for Australia. The actual number of new species will be confirmed once more detailed taxonomy is completed. Fish surveys documented 301 species of fish with many being new records for the Torres Strait region.
- Surveys showed that in general Torres Strait reefs are in good to excellent condition with high coral cover, presence of the major taxonomic and functional groups and minimal incidence of coral disease. However, small-scale outbreaks of crown-of-thorns starfish (COTS) were observed and, in an area that was re-surveyed, some of the more temperature sensitive species seemed to have declined.
- Data from a decade of satellite imagery was compiled into monthly averages allowing temperature anomaly maps to be produced that indicate areas of unusually warmer or cooler temperatures. These maps showed that the region was generally cooler than average for the project period as well as allowing for the linkages between conditions in the Torres Strait and those in the Pacific to be better understood.
- A coral bleaching temperature/exposure threshold and climatology was developed for Thursday Island based on 15 years of logger data. These give, for the first time, empirical measures of what conditions lead to coral bleaching for the reefs around Thursday Island and allows for the current bleaching risk to be derived from the real-time data, giving managers daily information on current risk.
- Using the logger based climatology and bleaching thresholds as a baseline, the ocean monitoring and satellite data showed that overall temperatures were cooler than the long-term mean reflecting global La Niña ocean weather patterns. As a result, no coral bleaching was predicted or observed for the Torres Strait for 2011 – 2014. Current Pacific Ocean weather however is showing a return to El Niño conditions that are characterised by hot dry summers with much greater risk of coral bleaching and other temperature related stresses.

A core part of the project has been the involvement of the local TSRA Land and Sea Management Unit Rangers in fieldwork. This included extensive training in reef survey methods, logger deployment and exchange, and in first level diagnostics for the ocean monitoring stations. There is now regional capacity that can be used as a basis for future work to monitor local reefs and to maintain the logger and real-time ocean systems.

In tandem with the capacity building work has been engagement with the local communities. The real-time ocean data has been made available via a series of dedicated data kiosks located in the window of a store on Thursday Island, in the council building on Masig Island and at the local radio station (4MW) on Thursday Island for broadcast use. All data and information from the project is available through the Torres Strait eAtlas web site at: http://ts.eatlas.org.au/nerp-te/gbr-aims-monitoring-torres-strait-coral-2-3.

The work has laid down the foundation, in terms of knowledge, skills and expertise, to put in place a framework for on-going monitoring and management of Torres Strait reefs by the TSRA Land and Sea Management Unit. In the context of the decline in corals in the southern GBR, this framework becomes a critical part of ensuring the long-term sustainability of Torres Strait reefs.

Project Outcomes

The project had a number of set goals; this section briefly describes the delivered outcomes against each goal.

1. *Build on extensive previous surveys of reef resources by the CSIRO [CMAR] by adding information on biodiversity and conservation value for a range of sites representing the various different types of reefs and regions of the Torres Strait seascape. Biodiversity surveys to involve LSMU staff and draw on local knowledge.*

Two biodiversity fieldtrips were undertaken as part of the project, the findings of the surveys are summarised in this report with the full results available as a technical report on the NERP TE Hub website. The fieldtrips included extensive training of local TSRA Sea Rangers with input into site selection based on local knowledge.

2. *Consult with TSRA and community to design a monitoring program for reefs of Torres Strait that addresses community needs.*

The design of the initial biodiversity surveys was done in consultation with TSRA based on existing knowledge and community needs. The initial surveys have resulted in a draft reef monitoring plan (see Appendix 1) that addresses community needs through a phased monitoring approach coupled with early warning systems to identify areas and times of potential reef stress.

3. *Involve TSRA LSMU rangers in field activities and train them to the extent possible so that they can continue the reef monitoring program once this project is completed.*

Training and capacity building was a core part of the biodiversity surveys, logger deployments and monitoring station deployments with local Sea Rangers completing core training and in-field training. Rangers were involved in all activities including logger deployments and exchanges, non-diving aspects of the biodiversity surveys and deployment of the real-time stations. Limitations on diving meant that Sea Rangers could not be used for any SCUBA based activities.

4. *Establish a data management system for data capture and delivery of appropriate and useful data products using the e-atlas.*

A location-specific component of the eAtlas has been established for the Torres Strait (see: http://ts.eatlas.org.au/ts) for the delivery of data and data products in the region. Additional data kiosks have been developed and deployed to give customised access to the real-time ocean and weather data with one kiosk located in a shop in Douglas Street, Thursday Island and another at the Council Building on Masig Island.

5. *Establish an early warning system for coral bleaching based on the best-available knowledge of bleaching thresholds and a real-time environmental observing system for key parameters, including temperature and light. A real-time observing station will be located in the western Torres Strait. If funds allow (through operational savings), a second station will be built in the eastern Torres Strait.*

Three real-time monitoring stations were installed using project and TSRA funding, they include one at Thursday Island, one at Masig Island and one at Maizab Kaur (Bramble Cay). The data from these stations feeds into Bayesian models of coral bleaching to deliver nightly indices of current and forecast coral bleaching risk. These are communicated during the summer via weekly email alerts to environmental managers.

6. *Establish a network of non real-time temperature loggers at representative sites to capture the range of thermal regimes in the Torres Strait.*

Loggers have been installed at 14 locations with two logger change-overs during the time of the project. Both the initial deployments and change-overs utilised local TSRA Sea Ranger and LSMU staff. The initial data from the loggers is presented as part of this report.

7. *Provide regular updates on current coral reef conditions and summer forecasts for bleaching risk. These updates are a compilation of all available satellite and in-situ data together with forecasts from POAMA and NOAA bleaching risk models and will be provided to key stakeholders.*

The team at the University of Queensland produced monthly satellite-based current condition reports for the region. This part of the project involved compiling the existing satellite data into seasonal average products against which the current images and conditions could be compared. The key outputs are images showing the regional temperature patterns, temperature anomalies (warm and cool spots) and then linkage from the regional products into larger-scale coral bleaching risk models, including NOAA and POAMA models. The outcomes from this component are presented in this report.

8. *Transfer knowledge and technology to LMSU Rangers to exchange temperature loggers, perform diagnostics and basic maintenance of real-time monitoring stations and provide field verification of bleaching.*

Local TSRA Sea Rangers and LSMU staff were involved in the deployment and retrieval of the loggers and in the deployment and servicing of the real-time stations. LSMU staff were involved in the deployment of the Masig Island and Maizab Kaur stations. During the installations training was done on the first level fault finding and maintenance of the stations.

9. *Identify ways in which the reef monitoring program might expand into additional sites and/or adopt alternative tools as capacity increases and should additional funds become available. Provide an assessment of the ability and, if necessary, additional requirements for the TSRA to be able to continue the reef monitoring after this project.*

A workshop was held at the Australian Institute of Marine Science (AIMS) on 9 October 2014 to bring together the main participants in coral monitoring in the Torres Strait, including TSRA, CSIRO and JCU. A report and set of recommendations from this workshop is included as Appendix 1 to this report.

Recommendations for Future Work

NERP project 2.3 successfully established the following:

- A base line of reef condition and status at key reefs in the eastern and central part of the Torres Strait, and local capacity to undertake future regular surveys to monitor reef condition and detect any changes to reefs.
- A set of real-time ocean monitoring stations, linked into expert systems, to monitor ocean conditions at three locations in the Torres Strait. The data from these feeds into local management and response activities as well as providing weather and ocean conditions to local communities.
- A network of logged temperature sensors that provide baseline data for a number of sites against which future change can be compared and detected.
- A regular set of satellite ocean images that document the overall temperature and water quality condition for the Torres Strait and that link into similar projects monitoring the global climate to allow for predictions of future conditions in the Torres Strait and the impact these may have on future conditions.
- A draft reef monitoring plan that includes local communities, in-region resources and expertise linked into data and modelling systems that provide a potential framework for an integrated reef monitoring plan for the Torres Strait.

These outputs combine to give a layered approach to monitoring and maintaining the reefs of the Torres Strait and the communities that rely on them. The reef surveys provide on-the-ground information about current conditions that can be compared against the measured baseline. The real-time ocean monitoring stations provide information about current stressors that may impact corals against the baseline of the logger data. The satellite information provides the highest synoptic information about larger-scale processes impacting the region and, combined with the ocean and reef data, gives a more complete picture of the status and threats to reefs of the Torres Strait.

There is a need to continue this work, especially in light of the current healthy condition of reefs surveyed, the documented decline in coral in the reefs of the Great Barrier Reef to the south, and an anticipated change in global weather to hotter and dryer El Niño conditions.

The following future work is proposed:

- Continued production of the monthly satellite images as operational tools for reef managers;
- Continuation of the logger program as a low-cost high-return method to determine thermal baselines for areas with currently no data;
- Continuation of the real-time stations with a view to create an overall network of five to six stations that cover a greater spatial area of the Torres Strait;
- Implementation of the draft Reef Monitoring Plan (see Appendix 1) including the development of apps and information systems to support TSRA Rangers;
- Investment in high resolution geo-coded underwater video and transect surveys of key reef areas as a permanent record of the current status of selected representative areas against which future change can be compared;
- Development of a joint project with AMSA/MSQ and key marine research agencies to better understand the oceanography of the region with a view to predicting future conditions from current measurements and to support the work of AMSA and MSQ;

- Development of a Scientific Advisory Group (SAG) within the TSRA LSMU to actively support and develop programs to facilitate greater opportunities for transfer of work and methods being done in the southern GBR to the reefs of the Torres Strait as a way to increase understanding of the reefs of the Torres Strait including how they connect with reefs to the north and south; and
- Investment in further development of local capacity for SCUBA-based reef monitoring.

The project has created a unique set of expertise and capacity within the region along with strong engagement between local communities and the main marine research agencies partnered through TSRA, and in particular LSMU. There is an opportunity to utilise the work and the relationships formed from this project to increase our knowledge of Torres Strait reefs and to work with local communities to manage these areas and the communities that rely on them.

1. Temperature Logger Program

1.1 Introduction

As part of NERP project 2.3: *Monitoring the Health of Torres Strait Coral Reefs*, AIMS established a long-term temperature monitoring program using inexpensive data loggers deployed at spatially extensive sites, representative of the Torres Strait (TS) region.

The aims of the logger program were to:

- Build a long-term record of sea temperatures in TS as a tool to monitor long-term changes.
- Monitor day-to-day sea temperatures at high resolution to identify the normal envelope of temperatures experienced by TS reefs and provide context to changes on coral reefs due to extreme temperature conditions.
- Provide a geographical overview of variation in sea temperatures across the TS.
- Develop locally relevant bleaching thresholds for TS reefs that can be used in conjunction with real-time observing stations to provide early warning of bleaching conditions.

Knowing the causes of impacts in coral communities is clearly advantageous in understanding and managing naturally dynamic systems. Sometimes the cause is obvious (e.g. storm or flood damage, COTS outbreaks) but other times it is not (e.g. coral bleaching or disease). Since coral bleaching and disease are often related to temperature stress in coral reefs, an accurate history of temperature is important.

Sea temperature monitoring commenced at Thursday Island at the Ports Corporation of Queensland jetty in May 1998 in a program funded by the Ports Corporation of Queensland. Funding for this program ceased in 2007 but AIMS has continued to monitor sea temperature to the present day. As a result, this dataset represents the longest dataset of sea temperatures in the TS (15+ years).

Loggers were deployed at an additional 14 locations as part of this project. This report details the deployments undertaken between 2011 and 2014 and a brief overview of results to date and their implications.

1.2 Logger deployments 2011-2014

Fifteen reefs were earmarked for logger deployments during this project. Of these, 14 were established. One site in the Warrior Reefs and a possible extra site at Ormond Reef are planned but have so far not been established due to vessel availability. The list of sites currently with loggers is shown in Table 1.1. Detailed site descriptions with photos have been produced for each site in PDF format to aid future logger exchanges and supplied to TSRA.

Loggers were exchanged in December 2012 at Bramble Cay and in December 2013 at Booby Is, Cherepo Is, Twin Is, Dugong Rf, Woiz Rf, Mer Is and Bramble Cay.

Table 1.1: Logger locations, site names (as per the AIMS temperature database) and deployment details. The letters "FL" in the site names generally refer to shallow, reef flat deployments whereas "SL" refers to slightly deeper reef slope deployments. GPS positions are in decimal degrees, taken whilst snorkeling directly above the loggers.

Location	Site name	First Deployment Date	Latitude	Longitude
Thursday Island	THUFL1	12-May-98	-10.586450	142.221667
	THURSL1	12-May-98	-10.586450	142.221667
Bramble Cay	BRAMBLEFL1	14-Dec-11	-9.140151	143.875308
	BRAMBLESL1	14-Dec-11	-9.139720	143.875883
Booby Island	BOOBYFL1	3-Oct-12	-10.603117	141.911283
	BOOBYSL1	3-Oct-12	-10.603065	141.911334
Cherepo Island	CHEREPOFL1	3-Oct-12	-10.689335	142.279912
	CHEREPOSL1	3-Oct-12	-10.689499	142.279299
Dugong Reef	DUGONGFL1	3-Oct-12	-10.517971	143.099692
	DUGONGSL1	3-Oct-12	-10.517638	143.099712
Moa Island	KUBINFL1	4-Oct-12	-10.238851	142.217604
	KUBINSL1	4-Oct-12	-10.238847	142.217569
Mabuiag Island	MABUIAGFL1	4-Oct-12	-9.950652	142.204592
	MABUIAGSL1	4-Oct-12	-9.950561	142.204421
Boigu Island	BOIGUFL1	4-Oct-12	-9.225283	142.221247
	BOIGUSL1	4-Oct-12	-9.225283	142.221247
Twin Island	TWINFL1	4-Oct-12	-10.462922	142.435821
	TWINSL1	4-Oct-12	-10.463059	142.435744
Warraber Island	WARRABERFL1	5-Oct-12	-10.200850	142.819110
	WARRABERSL1	5-Oct-12	-10.200690	142.818940
Iama Island	YAMFL1	5-Oct-12	-9.892490	142.764140
	YAMSL1	5-Oct-12	-9.892700	142.763440
Mer Island	MERFL1	5-Oct-12	-9.913355	144.040562
	MERSL1	5-Oct-12	-9.913136	144.040285
Woiz Reef	WOIZFL1	5-Oct-12	-10.174362	143.226408
	WOIZSL1	5-Oct-12	-10.174094	143.225992
Erub Island	ERUBFL1	No info	No info	No info
	ERUBSL1	No info	No info	No info
Masig Island	MASIGFL1	27-Jul-13	-9.758255	143.398629

1.3 Methods

Loggers were calibrated prior to deployment using a Guildline 5010 programmable water bath and a Fluke 1590 Super thermometer at 17 temperatures between 16° and 34°C. A linear slope and offset were calculated from these data which are used to post-process the downloaded data to achieve a final temperature accuracy of <0.1°C.

Loggers are deployed on concrete blocks with a 316 stainless eyebolt epoxy-glued into them to which the loggers are attached. Deployment depths were ~1 to 3.5 m and generally within 50 m of the shore to enable easy snorkel recovery and exchange of the loggers.

Loggers were set to record at 10-min intervals and turn on when a depth threshold of 0.5 m is exceeded. At this recording interval the loggers will have adequate memory capacity to record for 10 years and, in theory, enough battery power to last ~8 years. In practice however, there is a significant risk that other factors prevent successful data retrieval. The main issues are physical loss of loggers due to cyclones and storms and logger malfunction due to fouling organisms getting inside the sensors, or fish biting through the logger casing. To mitigate against fouling and fish bites, loggers are protected with a rubber sleeve and have 10 μm mesh covering the sensor holes. Future logger changeovers are recommended to take place at six-month intervals at island community sites and no longer than 12-month intervals at other sites.

All data are archived by the AIMS Data Centre and made publically available through a web-interface at http://data.aims.gov.au/aimsrtds/datatool.xhtml

Figure 1.1. Loggers are deployed on a concrete block with a stainless eyebolt and a small sub-surface buoy to aid recovery. The rope and buoys on these blocks will need to be replaced every two-three years.

1.4 Results

1.4.1 Thursday Island and a bleaching threshold

Fifteen years of temperature data for Thursday Island shows no significant warming trend. Most summers peak between 30.7 and 31.2°C and this is remarkably constant across years, except for the bleaching year of 2010 when the summer peaked at 31.5°C (Fig 1.2). The 2010 summer was marked by an unusual period of cloud-free days in mid-late February, which in combination with low winds led to additional warming of shallow waters.

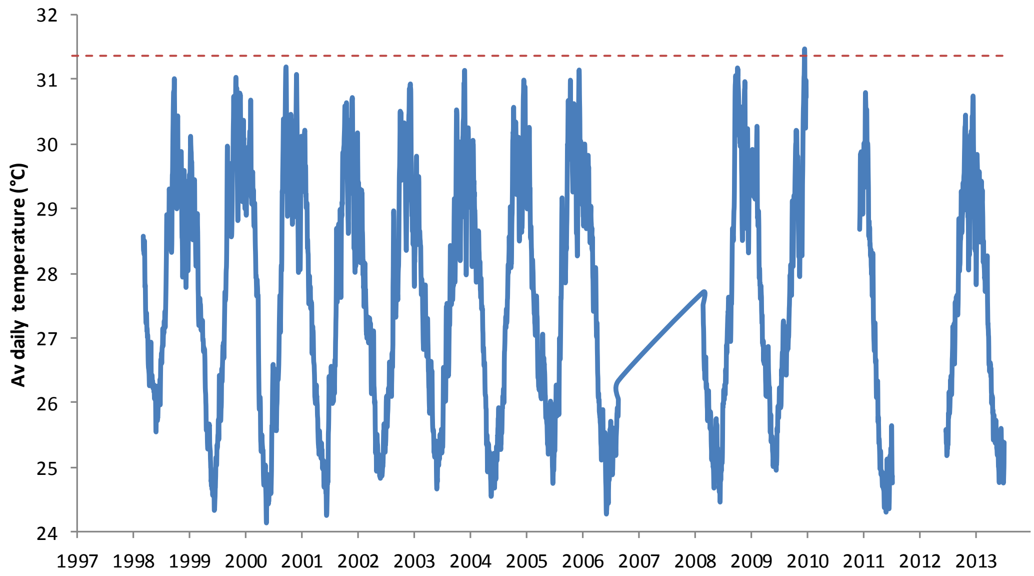

Figure 1.2. Fifteen-year temperature record for Thursday Island (mean of shallow and deep loggers). The dashed line separates the bleaching summer of 2010 from previous non-bleaching summers which peaked only 0.3°C below the 2010 summer.

A bleaching threshold for Thursday Island was determined by summing the number of days that temperatures were at, or higher than, preselected temperature increments. Using this time-temperature space, the warmest non-bleaching summers could be separated from the 2010 bleaching summer. The bleaching threshold was taken to be the time-temperature curve equidistant between these lines (Fig 1.3). Thus, according to this threshold, 7 days of average daily temperatures above 31°C would be sufficient for bleaching to commence and so would 3 days above 31.2.

This bleaching threshold was implemented with data from the real-time observing station at Madge Reef to monitor for bleaching conditions during the 2013 and 2014 summers. The bleaching early warning system will continue beyond the life of this project.

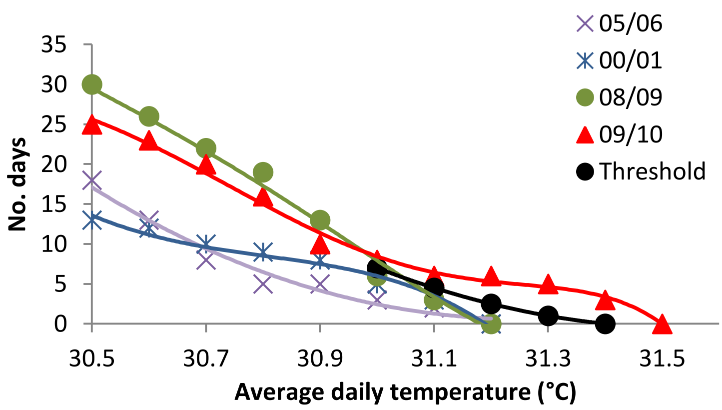

Figure 1.3. The bleaching threshold lies between the warmest (non-bleaching) summers of 2008/09 and 2000/01 and the (bleaching) summer of 2009/10.

1.4.2 Spatial sea temperature patterns in Torres Strait

One year of temperature data were obtained from loggers at six locations in the TS. These were spread from Booby Island in the far west to Mer in the far-east, and from Dugong Reef in the south to Bramble Reef in the north of the TS. Together with a 12-year climatology of remotely sensed SSTs from the MODIS (day + night passes) satellite, these data were sufficient to examine spatial and temporal temperature patterns in the TS.

The MODIS data reveal a distinct north-south gradient in average winter temperatures with reefs below 10.5° latitude distinctly cooler that those north of 10° latitude (Fig 1.4). No east-west gradient is apparent. However, average summer temperatures show a much less distinct north-south gradient but a very distinct east-west gradient (Fig 1.5). This east-west gradient manifests as warmer temperatures in the far-west cooling towards the east with a precipitous drop in the far eastern edge of the TS. Spatially, this cooling shows as a narrow band of cool water that is constrained to the reefs along the continental slope. Mer sits in the middle of this cool band of water, but Erub (only 45km to the NW) does not and nor does Bramble Cay.

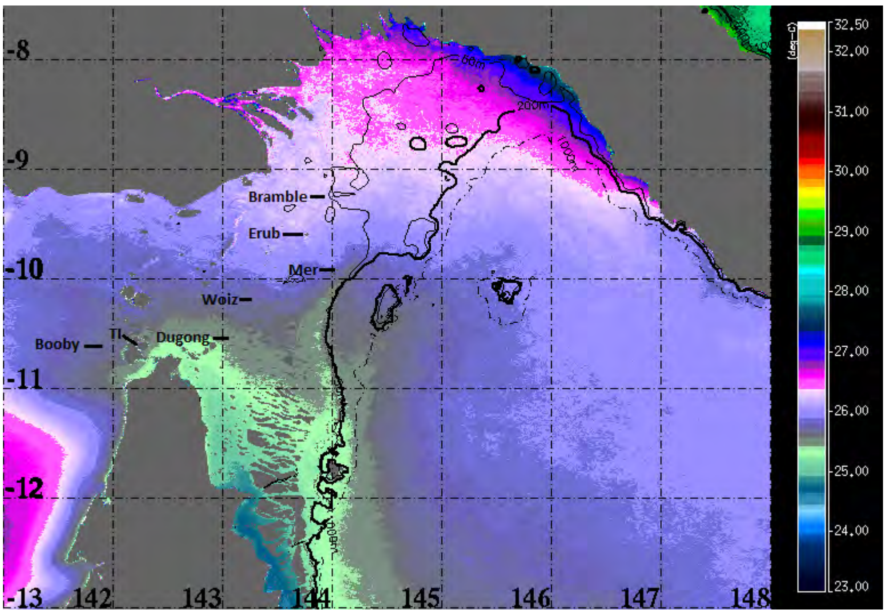

Figure 1.4. MODIS (day +night) climatology for the winter months of June, July and August for the period 2000 to 2012. Image supplied by S. Weeks and A. Redondo-Rodriguez (UQ).

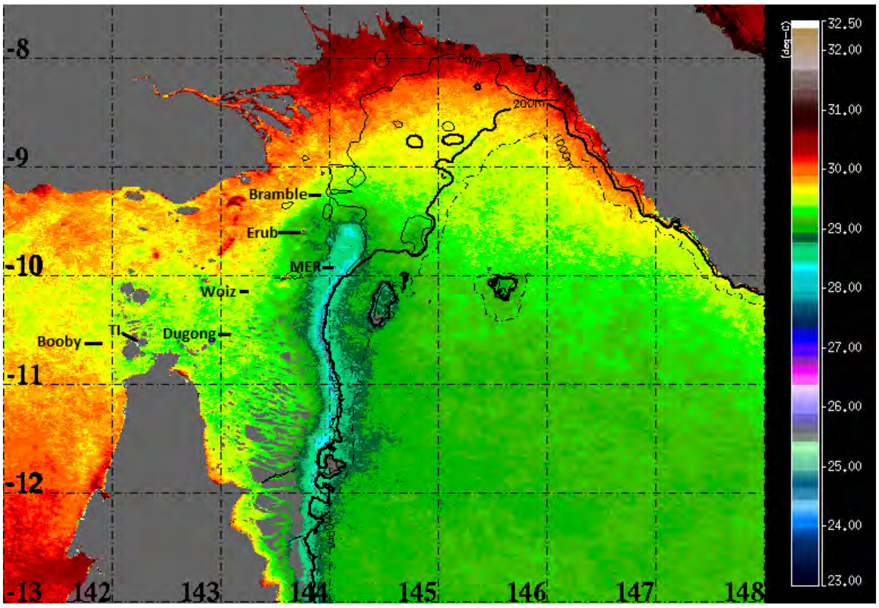

Figure 1.5. MODIS (day +night) climatology for the summer months of December, January and February for the period 2000 to 2012. Image supplied by S. Weeks and A. Redondo-Rodriguez (UQ).

The interpretation of the cool band of water in summer (less noticeable in winter) is that this feature is predominantly due to tidally induced upwelling (Thompson and Golding 1981). The large tidal run in the TS pulls water up from a shallow summer thermocline and this cold water is entrained in the tidal water and becomes partially trapped in the near-reef-edge waters (Nof and Middleton 1989). This has been shown to occur in similar reef passages near Lizard Island (Cahill and Middleton 1993) and the Ribbon Reefs (Wolanski et al. 1988) in the GBR. In winter, the thermocline is deeper due to strong monsoonal winds which cause the surface waters to be mixed to deeper depths compared to summer. As a result, upwelling is significantly reduced in winter. The Hiri current (the northern branch of the South Equatorial Current after it reaches the Australian coastline near Lizard Island) is likely to only play a small part (if any) in the shelf-edge cool water.

The magnitude of cooling is too large to be traced back to the Lizard Island area through advection alone. The direction of the Hiri Current is also not conducive to upwelling (in fact the opposite, i.e. down-welling would take place), however, there are ephemeral anti-clockwise eddies associated with the Hiri Current which could cause localised upwelling. The spatial and temporal extent of these eddies however cannot explain the spatial and temporal consistency of the band of cool water, hence eddie-driven upwelling can at best only have a minor influence. Similarly, reversals of the Hiri current due to strong NW winds in summer are too short to cause this consistent band of cool water.

Temperature logger data for 2012/13 show similar spatial and temporal patterns to the long-term MODIS climatology. Bramble Reef is the warmest site in winter and is consistently warmer than Mer, 85 km south (Fig 1.6a). Booby Island and Thursday Island are at the same latitude, but Thursday Island is consistently cooler, possibly because it is located between several other large islands (Horn, Prince of Wales and Hammond Islands) that radiate a large amount of heat into the atmosphere at night pulling air and shallow sea temperatures down in winter. This pattern is also borne out in the time-integrated temperature curves for the 2013 winter that show Bramble Cay as the warmest site and Thursday Island as the coolest site (Fig 1.6b).

Temperatures logger data for the 2012/13 summer are not easily interpreted simply based on latitude or longitude. However with the aid of the MODIS climatology, the spatial patterns in the logger data do make sense. Five sites (Booby, Bramble, Dugong, Woiz and Thursday Islands) appear to show similar summer temperatures despite being along wide latitudinal and longitudinal gradients in the TS, although each site displays slightly different amplitudes and variations (Fig 1.7). Mer Island is the only site that is clearly different (cooler) than the rest. Aside from being generally cooler, importantly, it also appears to miss the summer warm peaks displayed at the other sites (Fig 1.7a).

The other five sites are situated in the same MODIS green-yellow climatology zone and hence are indistinguishable from each other (with enough temporal averaging) and have very similar time-integrated temperature curves (Fig 1.7b). Based on the MODIS climatology, we would predict that future data coming from logger sites at Mabuiag, Boigu and Iama Islands will be warmer than at these five sites.

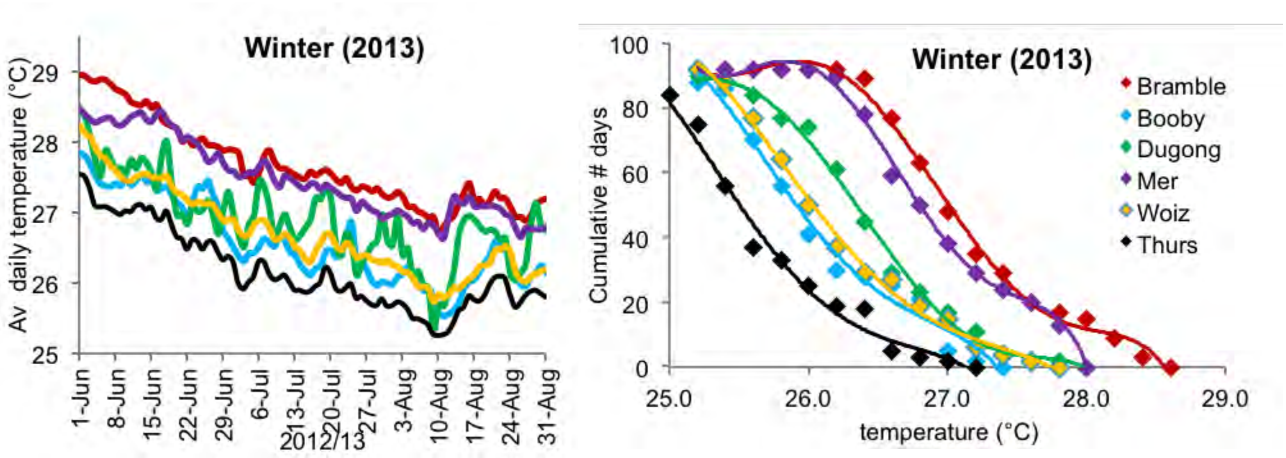

Figure 1.6. Logger temperatures for the 2013 winter shown as: (a) daily averages, and (b) cumulative number of days at or above the indicated temperature increments.

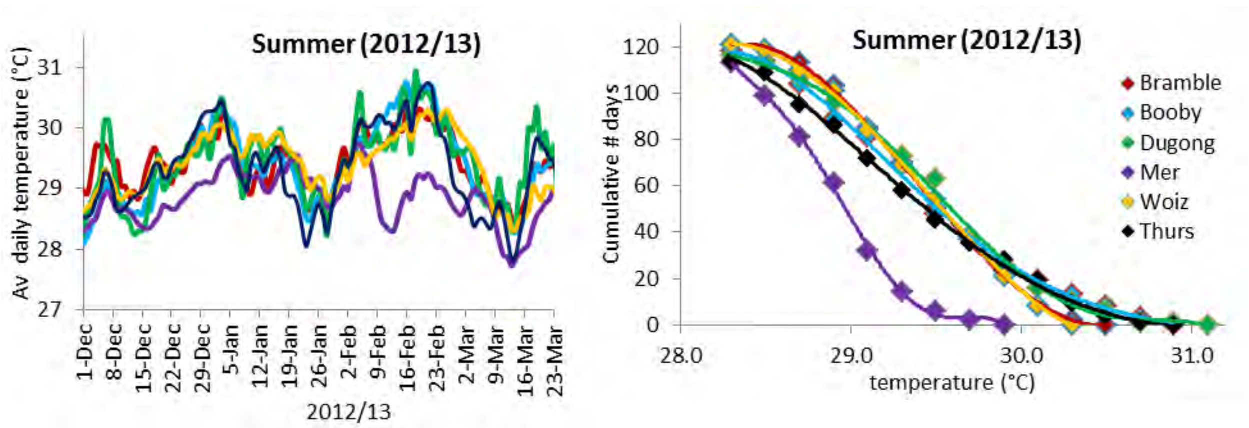

Figure 1.7. Logger temperatures for the 2012/13 winter shown as: (a) daily averages, and (b) cumulative number of days at or above the indicated temperature increments.

The implications of the spatial patterns in sea temperature are:

- Mer Island and reefs along the shelf-edge are likely to have a significantly reduced chance of bleaching compared to the rest of the TS. Since the predominant cause of the cooler water in summer is tidal upwelling, which is consistent, this area is likely to avoid anomalously warm summer temperatures. This upwelling signature also implies that the shelf-edge region of the TS experiences significantly greater nutrient input leading to higher productivity.
- The five sites with similar summer sea temperatures (Booby, Bramble, Dugong, Woiz and Thursday Islands) would be predicted to have similar bleaching thresholds. The logger data for Bramble and Woiz suggests that these two sites experience slightly fewer days above 30°C which may reduce their bleaching thresholds, but perhaps also their risk of bleaching if this is due to residual upwelled water. During the 2010 bleaching event, Erub sea temperatures were significantly lower than those of Thursday Island and no bleaching was noted (L. Evans-Illidge, personal communication).
- Despite the general similarity of these five sites, it is important to note that over shorter time scales (hours – weeks) there is still substantial variation between sites, which may be exacerbated during coral bleaching events when doldrums conditions prevail. As such, the logger program should not be discontinued at these sites.
- Given the importance of upwelling to productivity and reef ecology, it may be of interest to deploy additional temperature and perhaps chlorophyll loggers on the seaward side of Mer or Waier Islands to quantify the upwelling.

1.4.3 Depth and tides

The temperature loggers used in the TS (Sensus Ultra, Reefnet CA) are a dual-channel temperature and depth (via pressure) logger. As such they can provide useful data on local tides and these can in turn provide additional information in interpreting temperature trends.

While an analysis of tide data is beyond the scope of this report, the following examples are provided to illustrate the utility of the depth data.

Depth data to infer sea state

During low to moderate wind speeds, the tidal depth signature recorded by the loggers is a smooth pseudo-sine wave. During strong winds however (e.g. the period 3-6 March 2013), the normally smooth curve becomes jagged, particularly around the peaks and troughs (Fig 1.8). During these times, depth measurements are clearly highly variable as measurements coincide with peaks, troughs or in-between states of waves. A cursory overview of depth plots can therefore give a rapid qualitative indication of rough weather periods and when in the tidal cycle they occur.

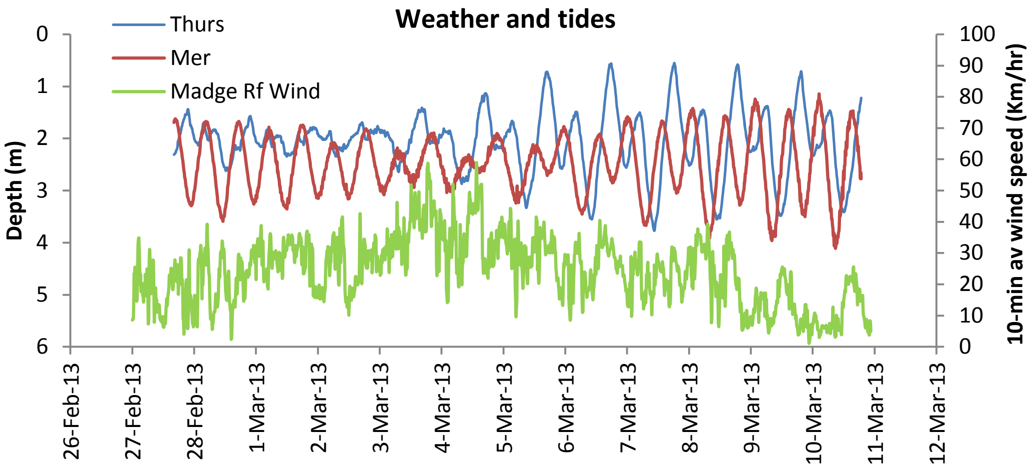

Figure 1.8. Wind speed at Madge Reef versus tide signal at Thursday Island and Mer recorded by the loggers.

Depth data to interpret temperature trends

A slightly wider time window around the strong wind period in March 2013 shows that a combination of winds and tides drove sea temperatures down and reduced diurnal variation at Mer (Fig 1.9). Up until early March 2013, temperatures at Mer showed strong diurnal variation. However, strong winds around 4 March 2013 and subsequently increasing tides caused sea temperatures to decline and diurnal variation to reduce. This period may have coincided with tidally-induced upwelling.

By 14 March 2013, the water column was well mixed and sea temperature variation greatly reduced. At this time, tides were also on the wane resulting in reduced upwelling and temperatures started to rise. Depth/tide data can therefore be of considerable help in interpreting temperature trends.

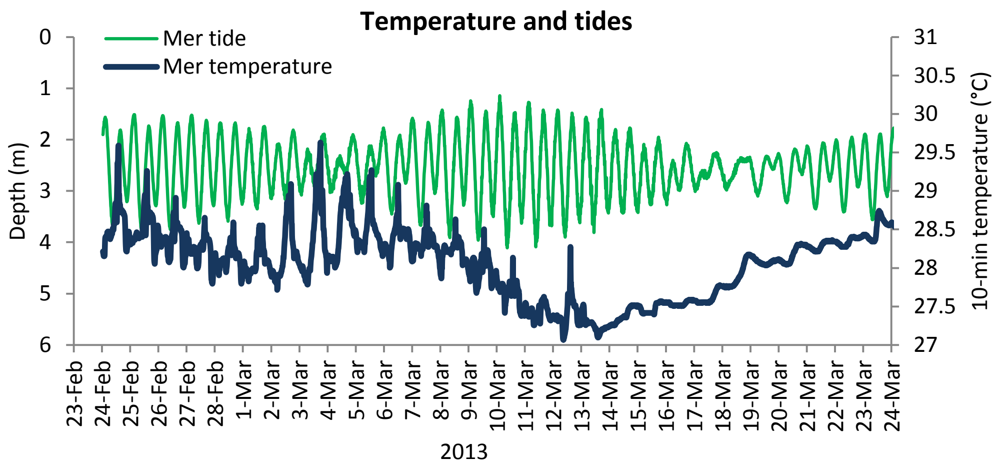

Figure. 1.9. Tide signal and temperature at Mer recorded by the loggers.

Depth data to identify meteorological/oceanographic features

Occasionally, persistent meteorological features leave there signature on the oceanography of coral reefs. In one of the datasets examined, there was a 5-month period were the long-term equivalent of a ''storm'' surge was evident. At Dugong Reef in the south-central TS there was a 60 cm increase in the mean tide level which lasted from mid-March to mid-September 2013 (Fig 1.10). This increase in water level coincided with a changing of the wind direction from predominantly northerly to predominantly south-easterly. Air pressure was also consistently higher at this time at ~1015 HPa compared to ~1006 HPa at the end of summer (data not shown). The interpretation of this phenomenon is that strong winds which set in at the start of the SE monsoon season pile up the water at this reef causing a long-term increase in mean water height. Interestingly, other logger sites examined (Woiz, Mer, Thursday Islands) did not show this feature.

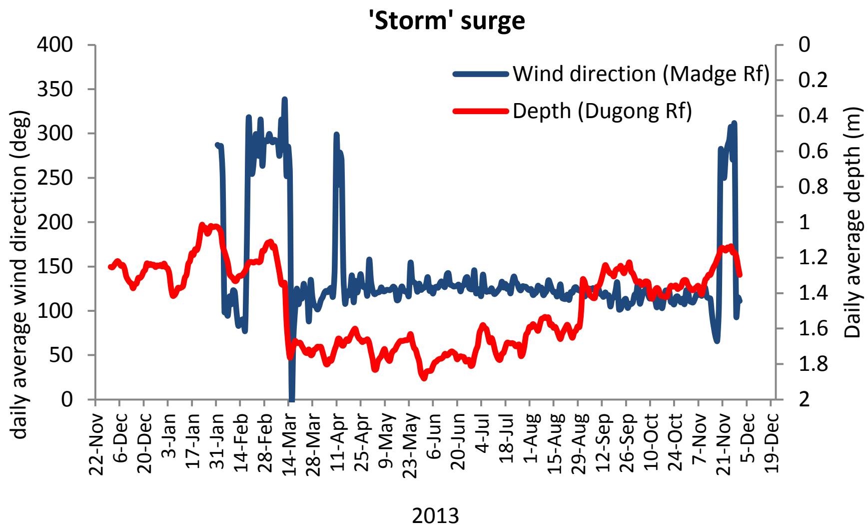

Figure 1.10. Daily averaged water depth at Dugong Reef shows a 5-month increase in mean water level of about 0.6 m between mid-March and mid-September 2013, consistent with a change in wind direction and the SE monsoon season.

1.5 Conclusions

1. Ocean temperature is strong forcing factor on coral reef communities. Although the TS avoided coral bleaching for decades (or longer) prior to 2010, this event highlighted that the TS is not immune from thermal stress and its subsequent negative (but unquantified) effects on coral reef condition.

2. A time-integrated bleaching threshold was constructed for Thursday Island based on 15 years of historical data. Spatial patterns in sea temperature in the TS suggest that this threshold may hold true for the central TS as well, but that thresholds are likely to shift out (become warmer) at the northern sites and shift in (become cooler) in the far eastern sites. These thresholds have already been implemented in an early warning system for bleaching conditions using the real-time observing stations at Madge Reef and Erub.

3. There is a persistent and spatially consistent band of cool water adjacent to the outer reefs along the continental shelf in the far eastern TS. This is attributed to tidally induced upwelling which is likely to bring with it nutrient-rich water from the Coral Sea. The ecological implications of the nutrient-rich water are undetermined at this stage but could be significant. The most immediate implication of this upwelled water is that Mer and surrounding reefs are likely to have a significantly lower risk of coral bleaching compared to the rest of the TS.

4. Depth and tide data obtained from the temperature logger program provide a rich source of additional information that can be used to interpret weather, temperature trends and unusual meteorological/oceanographic features. Where possible the depth channel should be continued in the temperature logger program in the future.

1.6 Literature Cited

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2. Biodiversity Surveys

2.1 Introduction

Torres Strait is a shallow, submerged land bridge between PNG and the northern tip of Cape York that includes an extensive area of shallow tropical continental shelf with at least 274 islands and associated reefs, plus many more shoals. The reefs of Torres Strait are a key component of the lives and livelihoods of local communities.

There have been many studies of the commercially harvested species in Torres Strait over several decades by the CSIRO (distributions summarised by Haywood et al 2007), and studies of the corals of Torres Strait reefs go back more than a century (Vaughan 1918). However, there have been no dedicated and detailed studies of biodiversity of coral reefs in Torres Strait, and there is no systematic collection of information on the ''health'' of reefs in the region that are important to local communities as sources of food and income. Compared to the GBR, little is known about the biodiversity of coral reefs in Torres Strait or about reef condition and how it has changed through time.

Consistent with the global situation for coral reefs, Torres Strait reefs are threatened by a variety of local and global agents – climate change, outbreaks of the coral-feeding crown-of thorns starfish (*Acanthaster planci*) (Murphy et al. 2011), increasing shipping traffic and increasing occurrence of coral diseases. Widespread coral bleaching was recorded for the first time in Torres Strait in 2010 (Bainbridge and Berkelmans 2014). Improved knowledge of Torres Strait coral reefs and monitoring their status and health will help identify problems and enable managers to respond accordingly.

The aims of this project were to update knowledge on coral and fish species that are found in the Torres Strait and to initiate a program to monitor the condition of reefs in the Torres Strait, involving staff from the TSRA Sea Management Unit so that they could gain experience in coral reef monitoring and be able to maintain a monitoring program into the future.

Fish biodiversity data was gathered using visual surveys while coral biodiversity data involved both visual surveys and limited collections of specimens. The monitoring component focused on sampling by snorkel using two survey methods: the Great Barrier Reef Marine Park Authority's Reef Health and Impact Surveys (RHIS) and manta tow surveys. The RHIS survey method is a component of the integrated Eye on the Reef Program of GBRMPA. It is used by staff of the Field Management Program from the GBRMPA and Queensland Parks and Wildlife Service (QPWS) for opportunistic surveys of sites on reefs across the Great Barrier Reef Marine Park. Manta tow surveys are used by the Australian Institute of Marine Science (AIMS) Long-term Monitoring Program (LTMP) for broad-scale assessments of coral cover on reefs, as well as for detecting causes of coral mortality such as bleaching and crown-of-thorns starfish (COTS) outbreaks.

The project involved two fieldtrips over two years. Members of the AIMS LTMP and a coral taxonomist from MTQ collected data on fish diversity in 2013 and coral diversity in 2013 and 2014. AIMS LTMP staff also trained TSRA LSMU staff in the manta tow survey method in 2013 and 2014. Accredited trainers from the GBRMPA and James Cook University trained the TSRA LSMU staff in the RHIS survey method in 2013 and 2014.

2.2 Methods and Results

A full technical report describing the methods, results and conclusions from the Reef Biodiversity surveys has been prepared as a product of this project:

Sweatman, H. P. A., Johns, K. A., Jonker, M. J., Miller, I. R., and Osborne, K. (2014) Final report on coral reef surveys in Torres Strait. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (47pp.).

The report is available from the NERP TE Hub web site, all data is lodged with the Torres Strait eAtlas (http://ts.eatlas.org.au/ts).

2.3 Discussion

The status of reefs in Torres Strait

This project has gathered data on a few representative reefs in the central and eastern Torres Strait so any inferences must be treated with great caution, and without a long-term baseline as a guide, it is impossible to draw conclusions about long-term trends. The obvious point of reference is the reefs of the GBR, but there are some important differences, such as a much lower incidence of cyclones in the more equatorial Torres Strait than most reefs in the GBR will experience (Puotinen 2004). The coral cover on the crests and slopes of the reefs that were surveyed in Torres Strait was moderate to high by GBR standards, as might be expected in a region with fewer cyclones. Coral disease was absent or at low levels in all sites except on the back reef at Mer, though this area had reasonably high coral cover. COTS were seen at all reefs that were surveyed by manta tow and were at outbreak densities (by GBR standards) at Aureed and at Waier and Dauar reefs. COTS have been known from Torres Strait for a long time; several COTS were recorded at Mer in 1913, but reports from CSIRO surveys (Murphy et al. 2011) suggest that COTS numbers have been increasing regionally in recent years. On the GBR, outbreaks follow a reasonably distinct pattern of spread but the timing and spread of COTS outbreaks in the Torres Strait have not been recorded. While COTS predation certainly reduces coral cover, the low human population in the region makes it unlikely that local human activities have caused the outbreaks and it is therefore not clear how they could be prevented.

Capacity Building

Trips in both 2013 and 2014 had specific advantages and disadvantages with regards to capacity building. In 2013, good weather and a higher trainer to ranger ratio produced effective training outcomes and set high expectations for future trips. A downside was insufficient capacity in the tender vessels, which slowed access to sites and reduced the time available for training. In 2014, the trainer to ranger ratio was lower and the weather was consistently rough. As a result, capacity building was restricted to reinforcing previous training where possible. Several TSRA rangers on their second trip in 2014 were able to pass on their knowledge of the RHIS techniques to others.

This project has made a start at building skills to establish and sustain long-term reef monitoring in Torres Strait but a number of issues remain to be addressed. To date, the focus has been on the central and eastern Torres Strait where the water is relatively clear. Effective techniques for monitoring reefs in the turbid waters and strong currents of western Torres Strait remain to be developed and trialled. A very important component of a monitoring program is data management and reporting. As part of the integrated Eye on the Reef program, the RHIS has an established data entry system and data base that will most likely be the tool for future monitoring in the region, while the Torres Strait eAtlas will have an important role in reporting and presenting the results. The joint workshop between TSRA LSMU staff, AIMS, CSIRO and JCU at AIMS in October 2014 canvassed these issues and made some recommendations.

An important consideration voiced by TSRA staff is the need for rangers to participate in surveys at frequent intervals (more often than once a year) in order to maintain their skills. This would fit well with the rangers based in communities using small TSRA boats to take advantage of calm weather to survey nearby reefs, rather than depending on an annual campaign using expensive charter vessels for a set period, regardless of the weather. A photo database has been created on the eAtlas to assist with maintaining the knowledge acquired during the project. Other resources online associated with the Eye on the Reef Program are also available to refresh skills.

Biodiversity of hard corals

While there is a long history of coral surveys in Torres Strait, the results from this project and the increasing perception of Torres Strait as an Australian biodiversity hotspot suggest that there are many more species to be discovered if appropriate resources were available to explore a full range of habitats and depths. Surveys of corals on the central and eastern reefs confirmed previous knowledge that the coral fauna is dominated by GBR species. It is likely that more species from the Coral Triangle will be found in the future, especially if the range of habitats surveyed is expanded.

There are insufficient data to determine if there has been any species loss since the collections in the 1970s and 1980s. Species in the MTQ collection that were not resampled by AIMS and MTQ in 2013 and 2014 come from a range of genera and they are mostly species that can only be identified from skeletons. In particular, there are numerous Montipora and Fungia spp. We have photographic records for some of these species from our recent surveys, but they were not included in the final species list as they could not be verified without a specimen. Any future sampling could focus on these species in the original collection that were not detected to ensure the baseline has not been modified.

Changing taxonomy is unavoidable when recording coral species. We have addressed this issue with two strategies. The assistance of Dr Paul Muir from MTQ in 2014 resulted in an expanded collection of specimens and the first collection of genetic samples from corals surveyed in 2014. Secondly, good quality photos of all the identified species have been databased, along with photographs of many corals that were only identified to genus. Reference photos of species are available through the eAtlas. A number of species recorded in 2013 (Osborne et al. 2013) are species that were described or bought out of synonymy by Veron (1999) and that have either recently been synonymised (e.g. Wallace et al. 2012) or are yet to be assessed by coral taxonomists. The reallocation of some corals, especially in the family Faviidae, to a new classification is not reflected here, but will need to be considered in the future.

Biodiversity of reef fishes

It is generally easier to identify reef fish species than coral species and even with the limited scope of surveys in this project we were able to increase the numbers of reef fish species that have been recorded in Torres Strait. While the AIMS surveys probably focused on small reef associated species to a greater extent than resource-orientated surveys by CSIRO did, hundreds of small cryptic species certainly remain undetected. The occurrence in Torres Strait of species like *Macropharyngodon choati*, that are common on reefs of the southern GBR but rare or unknown in the northern GBR raises further questions but there are likely to be many more species like *Halichoeres richmondi* whose centre of distribution is in the Coral Triangle to the north and whose range extends to Torres Strait.

3. Current Conditions Reports

3.1 Introduction

Timely information on major disturbances to coral reefs, such as thermal stress, is a major output of the project. Monthly updates, syntheses and forecasts of oceanographic and atmospheric conditions from satellites, models and real-time observing stations were provided to managers in the Torres Strait and Great Barrier Reef regions. The suite of data and parameters included presented in each monthly report is summarised in Table 3.1.

Table 3.1. Summary of data and parameters included in the Torres Strait and Great Barrier Reef environmental conditions report.

Data and Parameters	Source(s)
Recent sea surface temperature (SST) means and anomalies and in situ temperature evolution	MODIS satellite SST data NOAA NCEP Reynolds SST data AIMS operated IMOS Sensor Network
Recent means and anomalies of chlorophyll-a concentration (proxy for phytoplankton biomass)	MODIS satellite chlorophyll-a concentration data
Recent means and anomalies of Photic Depth (proxy for water clarity)	MODIS satellite Photic Depth data
SST anomaly forecast	Bureau of Meteorology – POAMA model
Coral Bleaching Outlooks	NOAA Coral Reef Watch models – based on SST predictions from: a statistical Linear Inverse Model (LIM-based), and a climate forecast system (CFS-based)
Surface conditions in the tropical Pacific	NOAA OISST[1]
Sea surface height anomalies	Ocean surface topography (JASON-2)
ENSO evolution and predictions	Bureau of Meteorology
15m Depth-Average Currents	CSIRO Bluelink Model

[1] Development server for this data has been taken offline from late second quarter 2014 – return to service schedule unknown.

3.2 Overview of environmental conditions: mid-2013 to November 2014

The latter half of 2013 was mainly characterised by neutral ENSO conditions across the tropical Pacific. In the Torres Strait, similar conditions with mostly neutral/below average temperatures were also experienced during this period. During the austral winter months, very strong South Equatorial Current inflow fed the North Queensland Current and a strong Papua New Guinea Gyre. In the central GBR, strong intrusions of oceanic waters onto shelf through the Palm and Myrmidon Passages were apparent while high anomalies related to a *Trichodesmium* bloom were observed in chlorophyll-a concentrations along the southern GBR during late 2013. This period concluded with an outlook of a continued ENSO-neutral and close-to-average sea surface temperature conditions over the following months.

In January 2014, the initiation of the development of an eastward-propagating Kelvin Wave across the equatorial Pacific became apparent in sea surface height and SST anomalies. The presence and progression of this wave resulted in an eastward displacement of positive SST anomalies in the Pacific and was associated with warmer than normal subsurface temperatures and the development of an El Niño event.

By April 2014, the equatorially-trapped Kelvin Wave reached the west coast of South America as shown in Figure 3.1. Associated increased oceanic heat content and the eastward propagation of a warm body of subsurface waters resulted in widespread positive SST anomalies over much of the eastern tropical Pacific. However, due to a lack of clear atmospheric response, ENSO neutral conditions continued in the Pacific through January to April although models continued to forecast 65% probability of a transition to El Niño conditions during the 2014 austral autumn or winter.

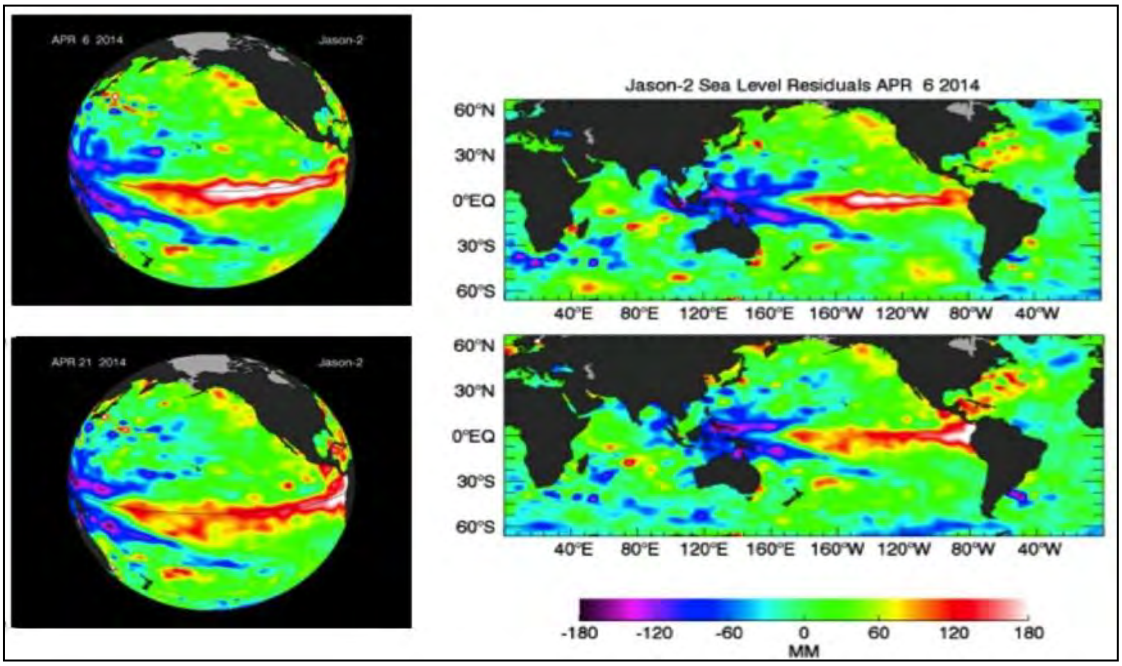

Figure 3.1. Sea surface height anomalies from ocean surface topography (JASON-2 Satellite) for 6 April 2014 (top panel) and 21 April 2014 (bottom panel) showing the intense eastward-propagating Kelvin Wave initiated in January, reached the west coast of South America in April 2014. The equatorially-trapped Kelvin wave is related to increased oceanic heat content and the eastward propagation of a warm body of subsurface waters that results in positive SST anomalies over much of the eastern tropical Pacific.

Regionally, SST conditions (based on MODIS and *in situ* temperature measurements) in the Torres Strait and northern GBR regions remained mostly below or close-to-average during the first quarter of 2014. NOAA Coral Reef Watch (CRW) products predicted no potential coral bleaching thermal stress. During May 2014, the Kelvin Wave in the equatorial Pacific continued to strengthen before dissipating considerably in June–July 2014. Hence, ENSO neutral conditions prevailed despite the tropical Pacific Ocean having been primed for El Niño over several months in 2014.

During the latter half of 2014, the Torres Strait and northern GBR regions experienced neutral to strong negative SST anomalies (Figure 3.2), as measured both by MODIS satellite and *in situ* seawater temperature instruments. In contrast however, NOAA CRW products indicated overall increased potential stress levels for the Torres Straits and GBR regions towards austral summer. Their climate forecast system (60%) predicted higher thermal stress levels, particularly for the GBR, indicating "Alert Level 1" potential stress.

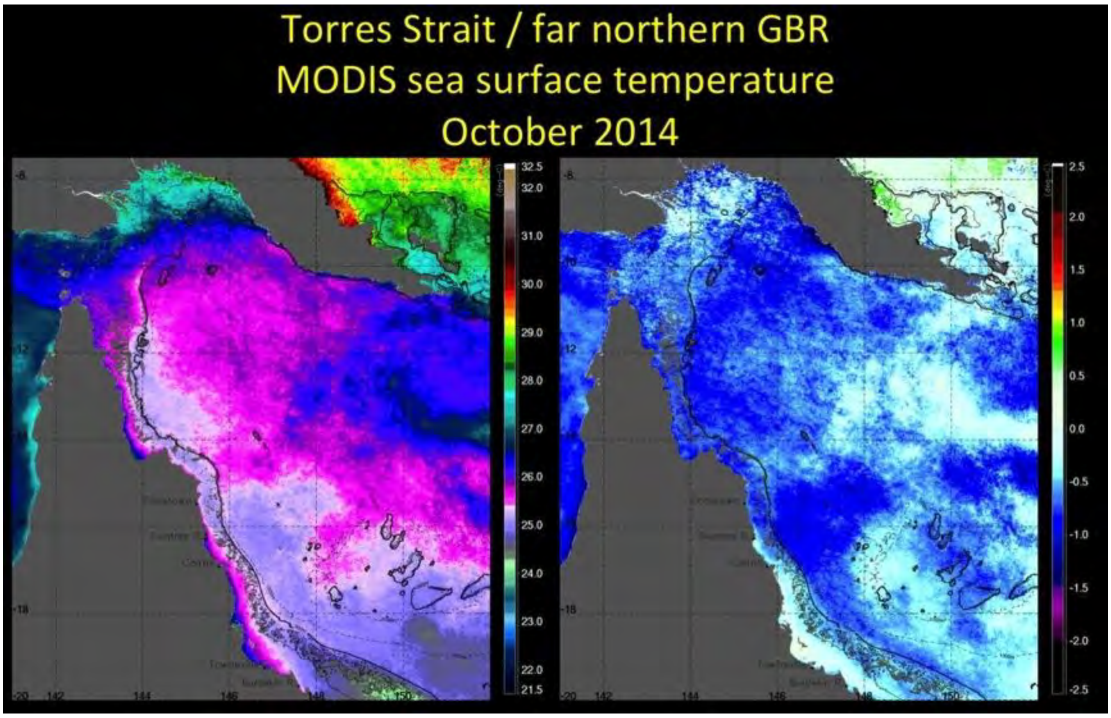

Figure 3.2. Monthly MODIS sea surface temperature for October 2014 showing strong negative SST anomalies in the northern GBR and Torres Strait regions.

Several features across the tropical Pacific remained characteristic of borderline El Niño conditions in the latter half of 2014. Recently (late October to early November), a new Kelvin Wave increased temperatures at depth in the central equatorial Pacific (Figure 3.3). These subsurface heat anomalies, however, remained lower than those experienced in April 2014.

Meanwhile, the NOAA CRW outlook has continued to indicate increased coral bleaching thermal stress for the GBR and Torres Strait regions for the 2014/15 summer (November 2014 to February 2015) (Figure 3.4). However, the consensus outlook released in early-November 2014 stated ENSO-neutral over the coming months (Figure 3.5) with weak El Niño conditions into early 2015, and close-to-average SST conditions.

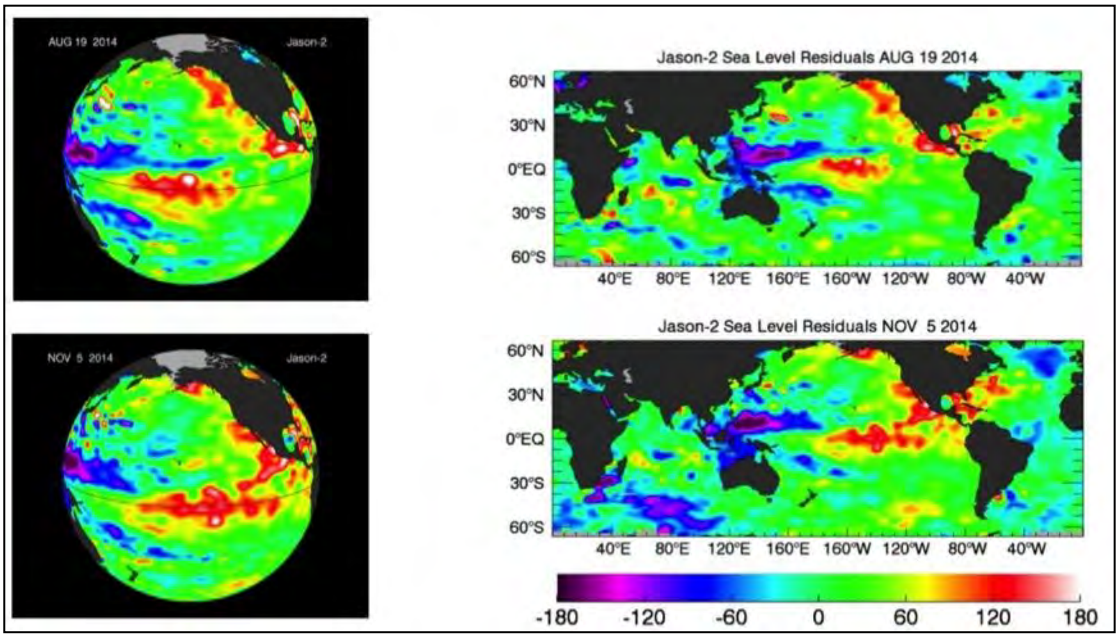

Figure 3.3. Sea surface height anomalies from ocean surface topography (JASON-2 Satellite) for 19 August 2014 (top panel) and 5 November 2014 (bottom panel) showing a new Kelvin Wave initiated in early November which increased subsurface temperatures in the central Equatorial Pacific.

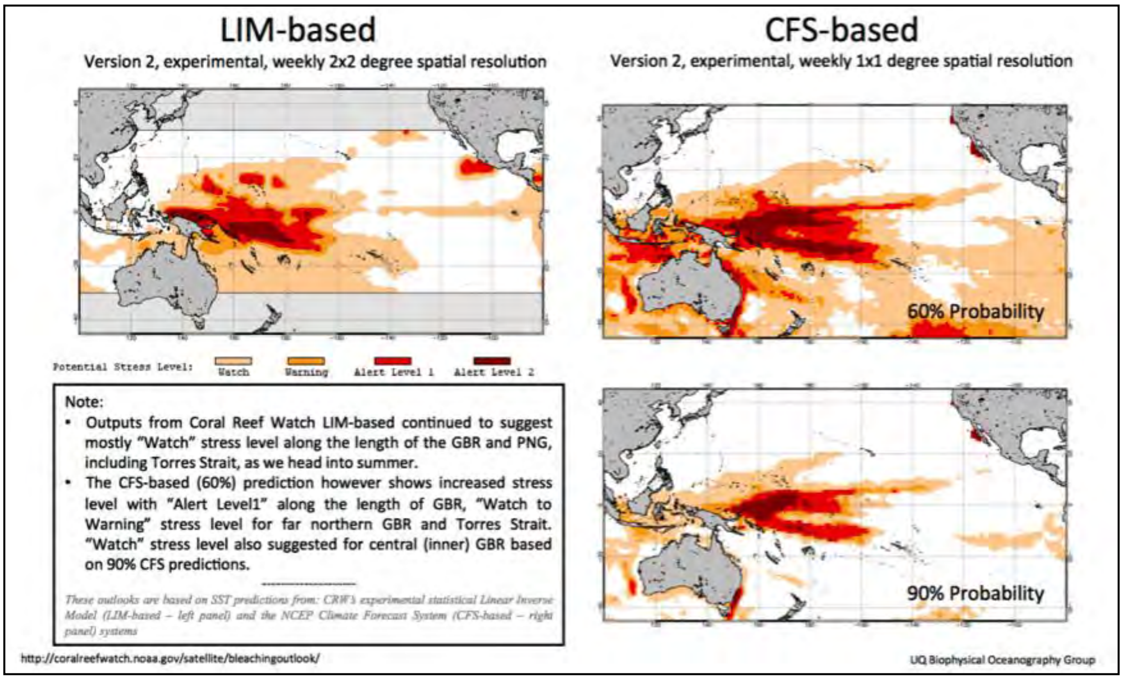

Figure 3.4. NOAA Coral Reef Watch (CRW) seasonal coral bleaching thermal stress outlook for November 2014 to February 2015 showing increased potential stress level for the Torres Strait and GBR regions.

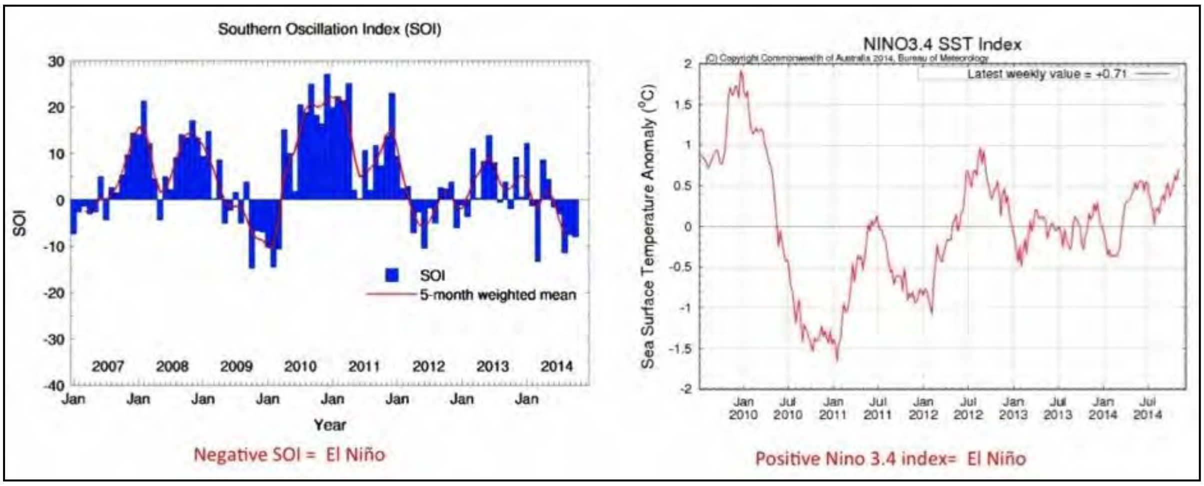

Figure 3.5. ENSO Indices including the Southern Oscillation Index (SOI, left) and Niño3.4 SST Index (right), showing the SOI has remained in a negative phase while the Niño3.4 index continued to show overall warming. These and existing surface conditions across the tropical Pacific suggest borderline El Niño conditions. Nonetheless, combined oceanic and atmospheric states still suggest ENSO-neutral conditions.

Note that the full set of monthly reports and associated images are available from: http://www.gpem.uq.edu.au/oceanography-reports

4. Real-time Stations

4.1 Introduction

The real-time monitoring component of the project provides real-time data for above- and in-water parameters giving information about potential coral bleaching events as they occur. Three stations were established during the project using a combination of project and external (TSRA) funding. The three stations are located at: (12) Madge Reef off Thursday Island, (2) Masig Island in the central east of the Torres Strait, and (3) Maizab Kaur (Bramble Cay) in the north-east TS. The Thursday Island station was installed in early 2012, the Masig Island Station in August 2013 and the Maizab Kaur one in August 2014.

The real-time stations were set up to provide:

- Real-time water temperature and light information as an early warning of potential coral beaching events;
- Development of system models to allow for predictions of future coral bleaching risk based on the current real-time data and future weather patterns;
- Real-time weather data to support local boating activities and as an information resource for local communities; and
- Detailed above- and in-water observations at key locations to allow for a greater understanding of ocean processes in TS.

For the Thursday Island (Madge Reef) station there was 15 years of logger data from a near-by location, this was used to build a climatology or average sea temperature model for the area that was used to identify times of 'unusual' temperatures. This, combined with the bleaching threshold developed in the logger component of this project, was used to contextualise the temperature data into times of 'normal' sea temperature and times of 'unusual' or 'abnormal' sea temperature. For the other stations, no such detailed historical baseline is available and so the data being collected now forms a new baseline for comparing future conditions.

Data from the stations was fed into two conceptual models of coral bleaching to produce indices of potential current coral bleaching risk and future bleaching risk. The current risk model uses current sea temperatures and light values along with bleaching thresholds to give an overall index of the current coral bleaching risk. The predictive model looks at the temperature trends and future weather predictions (via BoM weather forecasts) to try and predict the potential risk in the near future (days).

The model output and real-time data are presented on a number of websites targeted at different users, including the local radio station, public displays on Thursday and Masig Islands and an iPhone style weather app.

4.2 System Design and Deployment

The remote monitoring stations consist of an above water weather station (Valisala WXT520), light sensor (PAR or Photosynthetically Active Radiation sensor LI-COR Li192), communications modem and data logger, power systems including solar panels and a series of underwater sensors including two (shallow and deep) temperature sensors and a salinity (via conductivity) sensor.

4.2.1 Madge Reef (Thursday Island) Station

This station was installed on early 2012 on a channel marker located on Madge Reef in the channel between Thursday and Horn Islands. The equipment was designed to go over the existing navigation equipment and used the Telstra nextG network to return data. A photo of the station is shown in Figure 4.1 below.

The station was struck by lightning in late 2012 which required replacement of some of the equipment and it has suffered from some power issues that have resulted in data gaps. Even so, it has provided continuous data for the last three years. However the pole that the station was located on was damaged in August 2014 and the equipment had to be removed until the pole could be replaced. The station was re-established in December 2014 at Tuesday Islet on a more permanent structure.

Figure 4.1. Madge Reef (Thursday Island) station located on an existing channel marker.

4.2.2 Masig (Yorke) Island Station

A second station was installed on a 6 m galvanised pole on the eastern edge of Masig Island in August of 2012. While this station uses its own pole the design is the same as Thursday Island with an above water weather station and light sensor and in-water temperature and salinity sensors. It is hoped to add a turbidity sensor in 2015 as part of a Fly River monitoring program run by James Cook University. The station has operated reliably for the last two years; a photo of the station is shown in Figure 4.2.

Figure 4.2. Masig Island weather station.

4.2.3 Maizab Kaur (Bramble Cay) Station

This station was funded and installed as part of a larger project to look at Fly River influences and to capture image information on nesting turtles and seabirds on Maizab Kaur. Two poles were installed, one in-water and one on the Cay, with the weather station and light sensors on the land based pole and the in-water sensors on the in-water pole and a radio link between the two. A camera will be installed on the land pole and additional turbidity sensors on the in-water pole. It is hoped to have this completed by the end of 2014.

The Maizab Kaur station currently uses 3G phone communications (Telstra nextG®) but this is at the extreme edge of communications range and so data is currently only returning daily or as the radio reception allows. An upgrade to the 3G-reception in the area is expected in 2015, otherwise satellite communications may be installed if the phone reception doesn't improve. As this station is still being established no data from this station will be included in this report.

Figure 4.3. Maizab Kaur station – land based pole.

4.3 Methods

4.3.1 Data Delivery

Data from each of the stations is transmitted via the Telstra® nextG® network back to AIMS every ten minutes or as phone reception allows. At AIMS the data is quality controlled and inserted into a database; from there it is available via the AIMS web site at: http://weather.aims.gov.au/

As well as this general access website, four data kiosks have been developed and installed. These are located at:

- the TSRA Land and Sea Management Unit,
- the local radio station 4MW on Thursday Island,
- the window of a general goods store on Thursday Island, and
- the council building on Masig Island.

An example screen from the 4MW system is shown in Fig. 4.4.

Figure 4.4. Webpage showing real-time information for Madge Reef.

4.3.2 Climatologies

To give context to the water temperature data a climatology was built using temperature logger data from 15 years of observations at Thursday Island. The fifteen-year record was processed to give average daily temperatures for each day of the year (from 1 January to 31 December) along with the standard deviation and min/max of the historical data. This gave the long term temperature mean, the historical range of temperatures and a measure of how variable temperatures are for any given day of the year.

Using the mean average daily water temperature and the measured standard deviation of the temperature readings it becomes possible to define 'normal' water temperatures from the 15-year historic data set.

For this study this was set using the following:

Normal Temperatures: Daily Average Water Temperatures between the +2 and -2 Standard deviation limits from the historical mean temperature (statistically = 95% of the data).

Unusual Temperatures: Daily Average Water Temperatures between the +2 and +3 Standard Deviation limits from the historical mean or between -2 and -3 Standard Deviations from the historical mean temperature (statistically = 4% of the data).

Extreme Temperatures: Daily Average Water Temperatures greater than the +3 or less than the -3 Standard Deviation limits from the historical mean (statistically <1% of the data).

The standard deviation limits effectively define what are 'normal' temperatures, what are unusual and what are extreme. This simple definition allows the system to 'know' what readings to ignore because they are normal for that station and what readings to respond to because they are unusual or extreme for that station. The following responses were defined:

Normal Temperatures: Do nothing.

Unusual Temperatures: Alert local rangers, increase risk reporting from weekly to daily.

Extreme Temperatures: Issue wider area alerts.

The data used to develop the climatology for Thursday Island is shown in Figure 4.5, which shows the recorded historical minimum (blue line) and maximum (red line) temperatures, the long-term daily mean (black line), and a smoothed model of the mean (dashed purple line).

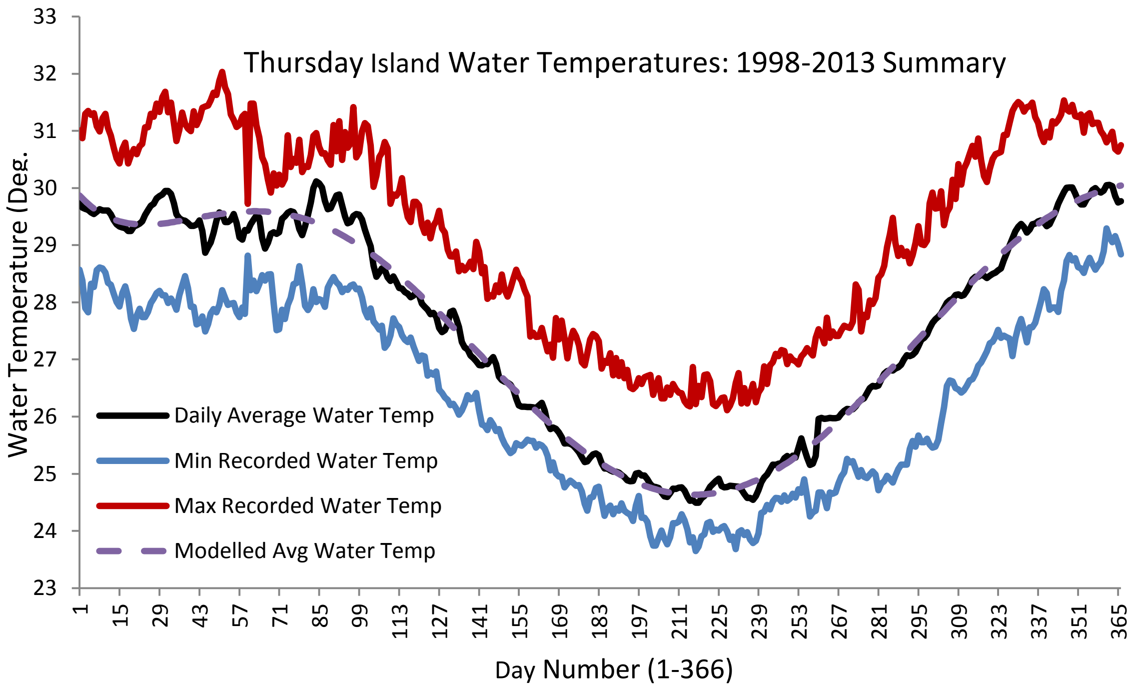

Figure. 4.5. Historical data used to construct the Thursday Island climatology.

The long-term data shows water temperatures are highest in late February early March and that summer water temperatures tend to be stable from December through to March, reflecting the summer monsoonal period. The maximum temperature recorded is 32.0 °C in late February and the lowest is 23.7°C in mid-August.

The mean water temperatures (black line in Fig. 4.5) was modelled to produce a smooth curve (dashed purple line in Fig. 4.5, r^2 of 0.94), this was used as the long-term mean water temperature or climatology for Thursday Island. The standard deviation was also modelled to produce a smooth curve and then the ± 2 and ± 3 Standard Deviation Limits from the modelled mean were overlaid to produce the final climatology as shown in Fig 4.6.

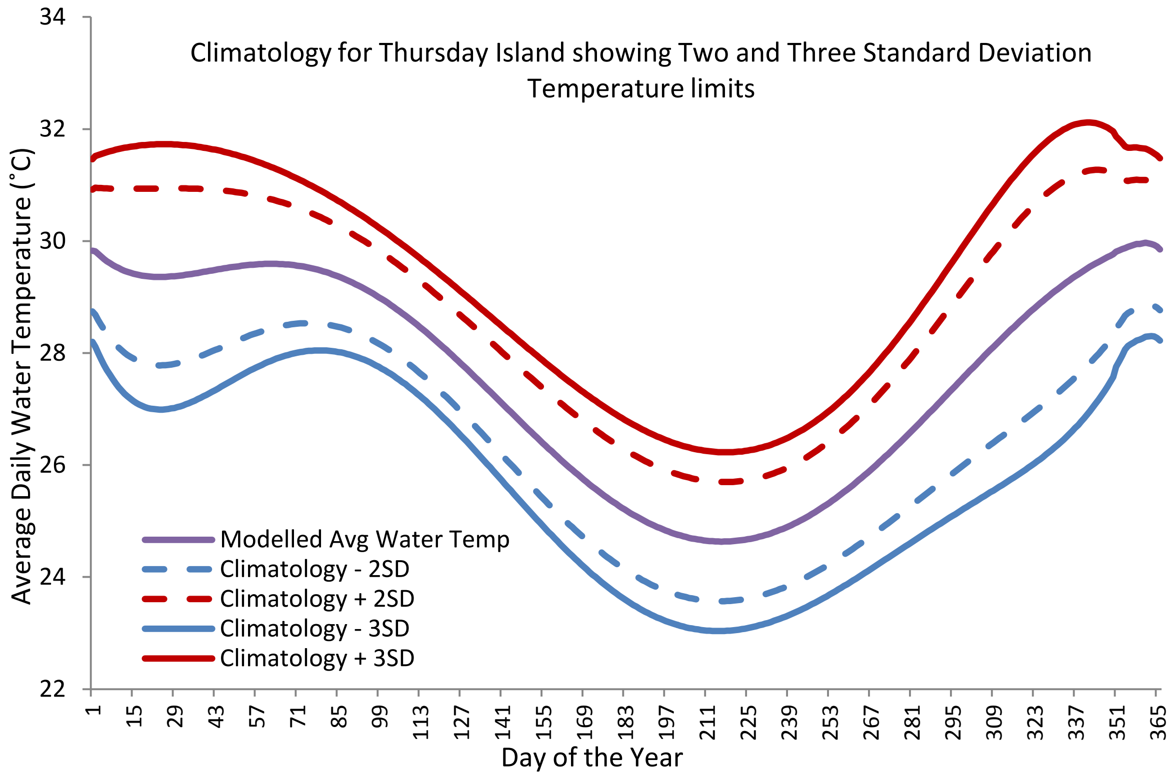

Figure 4.6 Climatology for Thursday Island showing the +/- 2 and +/- 3 SD limits.

From Figure 4.6 any daily average water temperature from the Thursday Island station that was within the dashed red and blue lines is considered to be 'normal', between the dashed and solid lines (the two and three standard deviation limits) as 'unusual' and above or below the solid blue/red lines as 'extreme'.

Climatologies have not been developed for the other sites (Masig and Maizab Kaur) as there is little historical data available although under this project that data collection has started.

4.3.4 Bleaching Risk Indices

The water temperature data is analysed automatically at the end of each day and then run through two Bayesian models to generate a current bleaching risk index and a forecast bleaching risk index. A weekly email is generated that summarises the current and predicted bleaching status for that week to alert resource managers to potential changes in bleaching risk for the sites being monitored. More regular updates and values can be found from the website developed for the TSRA Land and Sea Management Unit that shows graphically changes in conditions and bleaching risk.

4.3.4 Bayesian Models

Two Bayesian models were created to develop measures of coral bleaching risk. The first looked at current temperature and light conditions and how close these were to known thresholds that cause or increase the risk of coral bleaching. The second looked at how conditions were changing, using the data from the previous days and available forecasts for conditions for the next few days, to give an index of how the risk was forecast to change.

The current bleaching risk model (Fig 4.7) looks to measure and evaluate the main known drivers of environmentally caused coral bleaching; temperature and light. It primarily uses how close the current water temperature is to the known bleaching thresholds developed by this project. It does this by looking at the number of days at or over a series of temperature thresholds (for Thursday Island these go from days at or over 31.0 to 31.4 °C) to give a temperature stress value. It then looks at the current light conditions as the total amount of light received for the day and the amount over 1,800 µmol s^{-1} m^{-2} which is an empirical measure of high light to give a light stress value. Finally, it looks at the tide levels to identify times of low tide during the middle part of the day to give a tide stress value. The temperature, light and tide stress values are then modelled to give the final current bleaching risk value as a number scaled between 0 (no risk) and 1 (high risk).

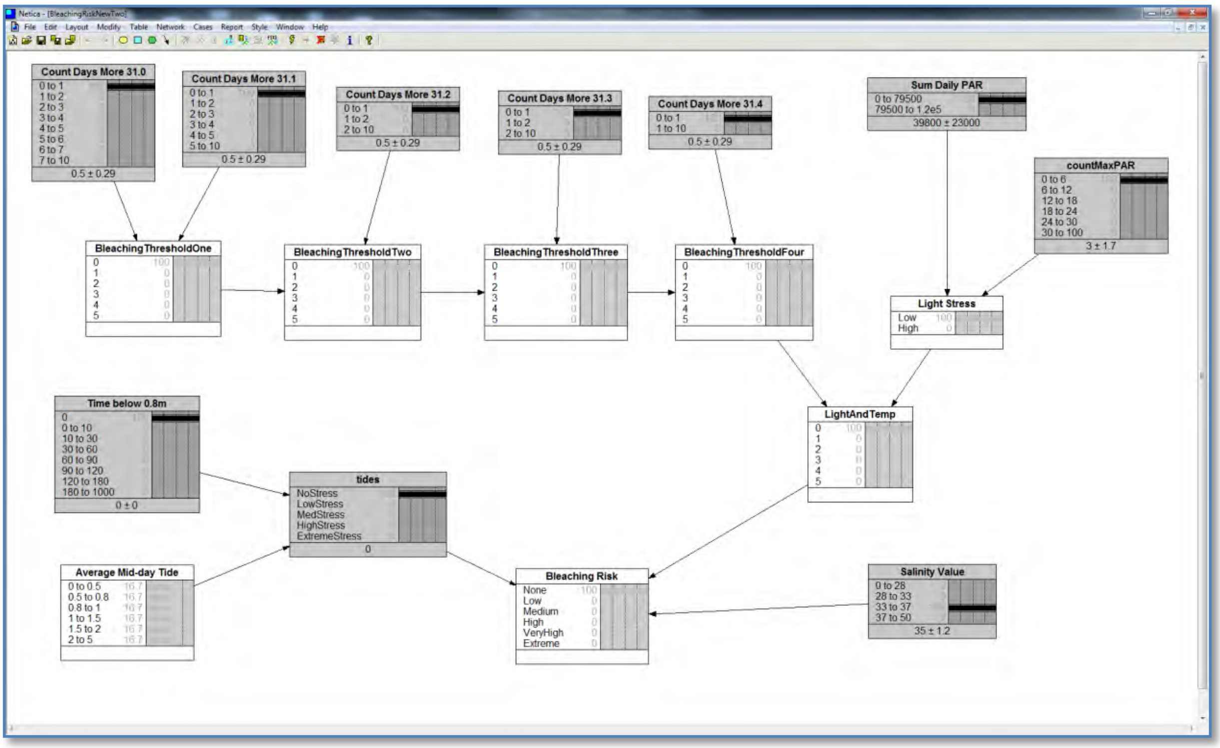

Figure 4.7. Bayesian Model of current bleaching risk, dark-grey boxes are inputted values from the daily real-time data, light grey boxes are calculated model values.

The bleaching forecast models work differently, it looks to identify if the ocean system will accumulate or lose heat and light over the next few days the idea being that if the system increases in heat/light then the risk of bleaching will increase, in the same way if the system looks to lose heat and light then the risk of bleaching should decrease.

The bleaching forecast model is shown in Fig 4.8. The model uses current water temperature, the change in water temperature from yesterday to today, the closeness of the current water temperature to the known bleaching thresholds, the current and forecast wind speeds (from the BoM website), the current and change in light levels, the amount of rain and the tidal information.

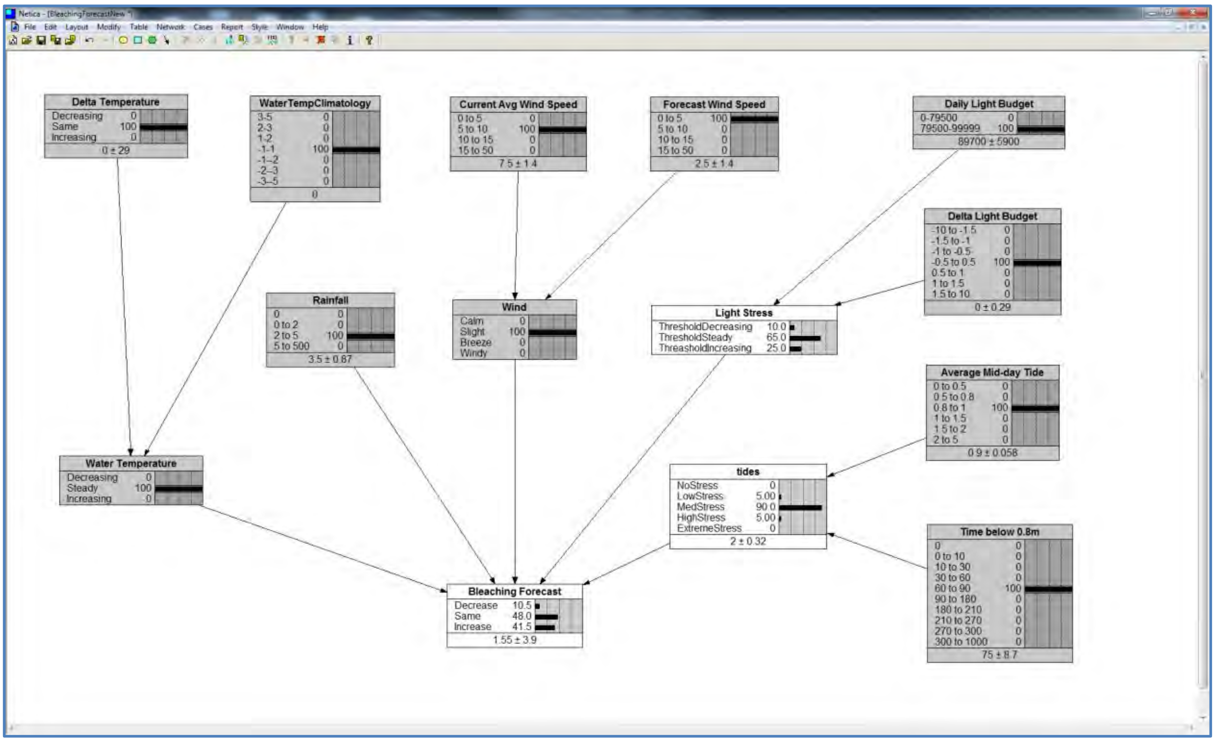

Figure 4.8. Bayesian Model of forecast bleaching risk, dark-grey boxes are values inputted from the real-time data or from forecast data, light-grey boxes are modelled or calculated values. The final index is scaled from -5 (risk decreasing) to 0 (risk staying the same) to +5 (risk increasing).

The model is based on a series of empirical understandings about what conditions lead to heat accumulation and loss in the water column and how these interact to increase or decrease the risk of bleaching in the near future.

Temperature: If temperature is increasing over the last three days then this increases the risk in the model, if it has been falling then it decreases it in the model. If the temperature is close to the threshold then the model is more sensitive to smaller changes in average temperatures than if it is below the threshold values.

Wind Speed: Calm conditions increase the heating of the water, previous bleaching occurred during doldrums conditions and so low wind speed increases the risk while high wind speeds lead to heat loss through wave-based mixing and surface convection.

Light: As with temperature, increasing light levels (as both the total amount of light in a given day and the time spent above the light threshold) increase the risk while falling light levels decrease the risk.

Rainfall: Rain tends to cool the atmosphere and hence the ocean and so large amounts of rain (more than 5 mm) tends to reduce the bleaching risk.

Tides: Low tides during the middle of the day when light and temperatures are at their maximum can lead to increased exposure for corals and hence bleaching risk, this parameter looks for tides below 0.8 m in the middle of the day as both the average mid-day tide and the time spent below 0.8 m during the day.

The model uses probability matrices between the various parameters to output a final future risk value scaled from -5 (risk decreasing) to 0 (risk staying the same) and +5 (risk increasing). Note that the current bleaching risk model and the forecast bleaching risk model are somewhat un-coupled, that is while the current risk is a parameter in the forecast model it is not the main parameter. This allows the forecast model to predict times of risk change independently of the current risk.

4.4 Results

4.4.1 Water Temperature

Madge Reef (Thursday Island)

The daily average water temperatures for Madge Reef are shown in Figure 4.9 and show that the maximum recorded temperature recorded was 30.49°C well below the bleaching threshold of 31.4°C, in fact the observations show that overall conditions were mostly within the 'normal' range as defined by the climatology with most daily averages around the long term mean. The summers were in particularly cool with the 2012/13 summer being well below the bleaching threshold.

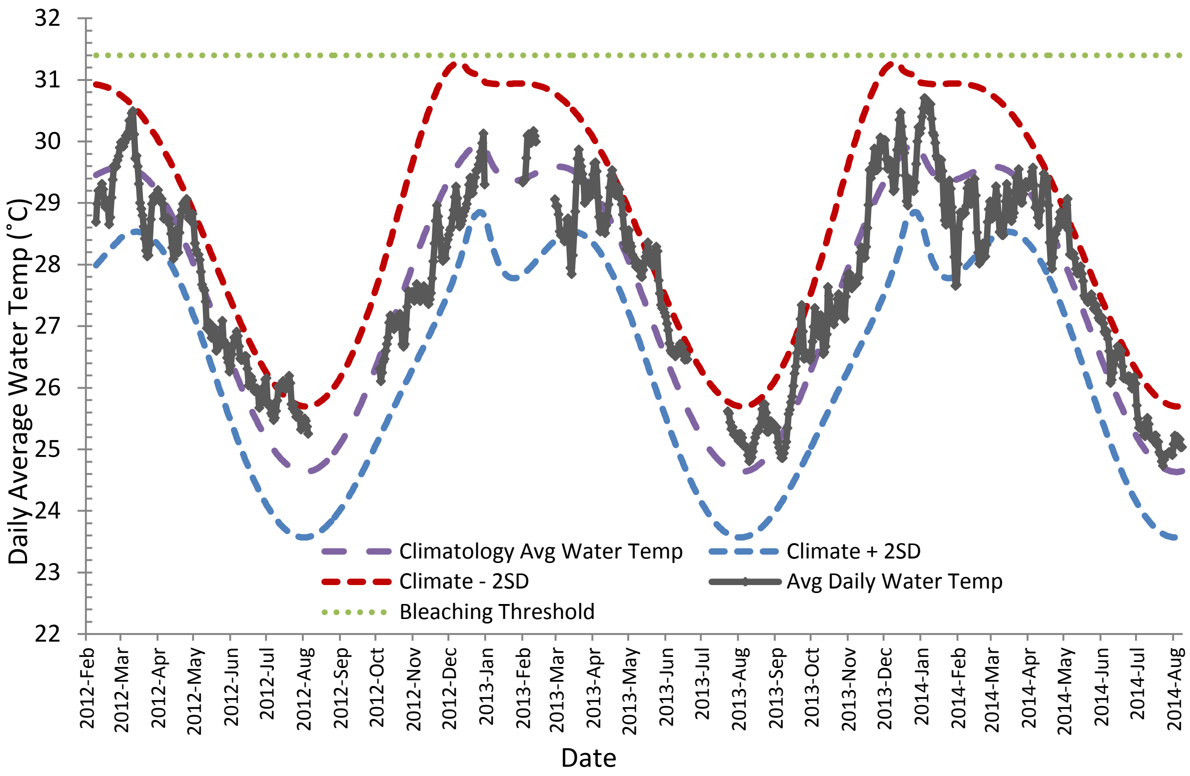

Figure. 4.9. Average Daily Temperatures from Madge Reef (Thursday Island) plotted against the developed climatology; the dotted green line is the bleaching threshold value.

The graph shows that temperatures only moved outside the 'normal' range (± 2SD from the long term mean) in late summer in 2012 and again in 2013 and 2014, indicating a somewhat delayed transition from monsoonal to winter weather patterns over the three years sampled from that of the long-term mean. The influence of the monsoon can be seen in the 2013/14 summer where temperatures remain high until late January 2014 when monsoonal rainfall cools the system (see Fig 4.19 for the rainfall patterns).

Masig Island

In general, the water temperatures at Masig Island (Fig 4.10) follow those of Thursday Island (TI) with temperatures leading up to the summer very similar but with a slower cooling as summer moves into winter post-monsoon. There is no historical data for Masig Island to construct a robust climatology but, using the TI climatology, temperatures were well below the TI bleaching threshold and mostly within the normal range.

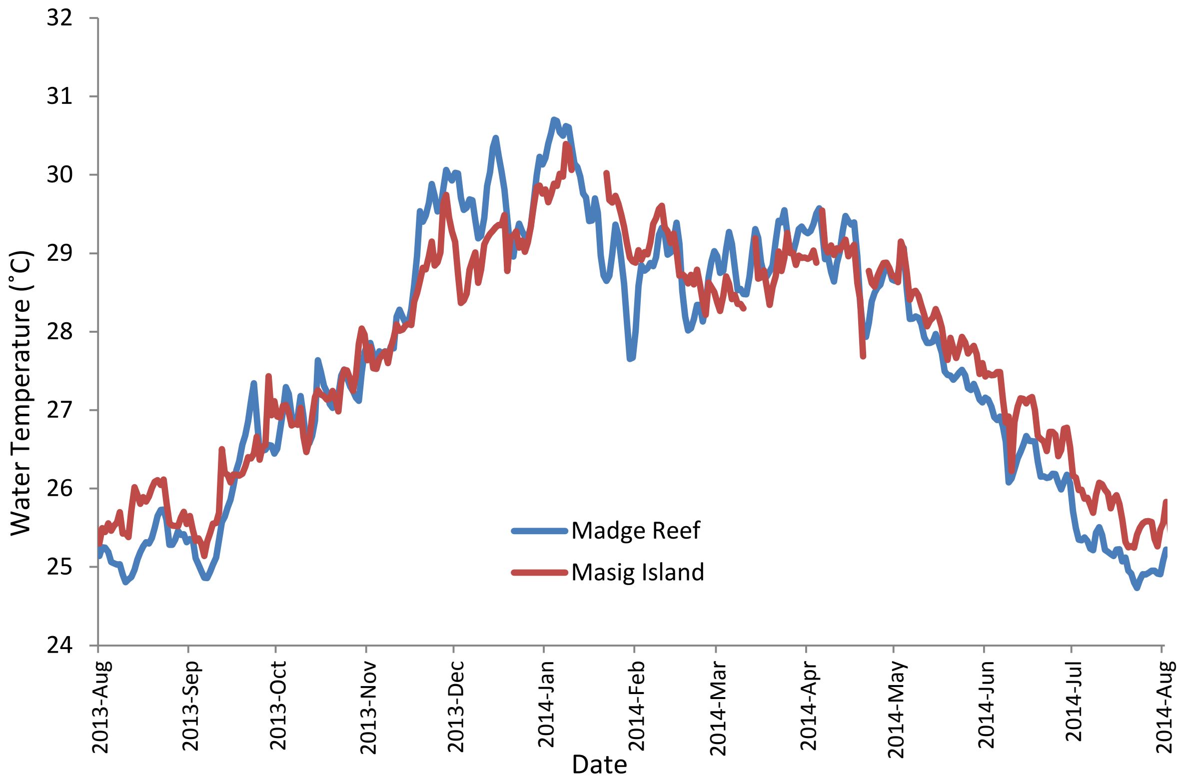

Figure. 4.10. Average Daily Temperatures from Masig Island overlaid with those from Madge Reef (Thursday Island).

Maizab Kaur (Bramble Cay)

At the time of writing the Maizab Kaur station is still being established and so no significant data is available for analysis or comparison.

Temperature Patterns between Masig Island and Madge Reef

Figure 4.10 seems to show a delayed cooling in water temperatures post monsoon at Masig Island against the data from Madge Reef. Figure 4.11 shows the difference in air and water temperatures between the two stations (positive values mean temperatures are higher at Thursday Island than Masig Island, negative values means temperatures are higher in the north than the south). The figure shows that in winter temperatures are warmer in the north at Masig Island over those in the south at Thursday Island (Masig is some 160 km north-east of Thursday Island) but that in the summer, from September through to March/April, it is warmer in the south at Thursday Island than in the north at Masig Island. The temperature difference is around 0.5˚C, that is Thursday Island is half a degree warmer on average during the summer and 0.5˚C cooler in the winter than Masig Island.

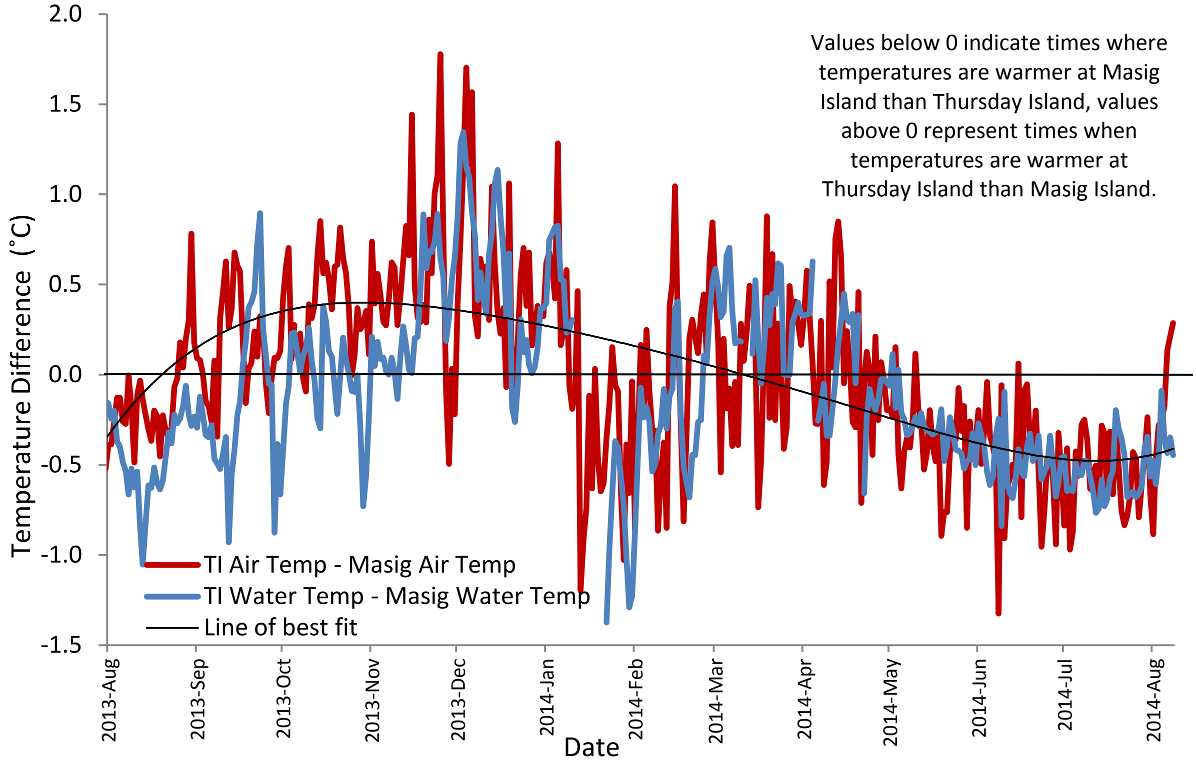

Figure. 4.11. Difference between air and water temperatures at Madge Reef (Thursday Island) and Masig Island.

Although there are distinct summer and winter differences, it is possible to co-plot temperatures from the two stations and to look at the relationship between them. Figure 4.12 shows that a linear relationship has an R2 value of 0.94 for some 360 points which is a reasonable fit. From this relationship it may be possible to utilise climatologies and bleaching thresholds from Thursday Island where this data exists to Masig Island. As the slope of the relationship is less than one this means that slightly lower temperature thresholds may apply for Masig Island, for example the zero-day bleaching threshold of Thursday Island (Fig 1.3) of 31.4˚C may relate to a threshold of 30.8˚C at Masig Island.

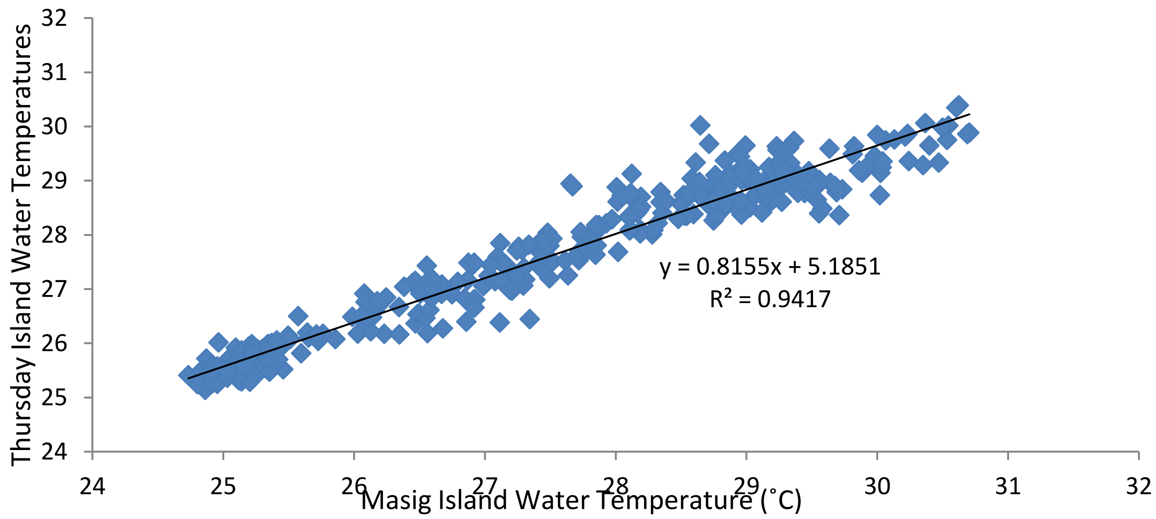

Figure. 4.12. Relationship between water temperatures at Madge Reef and Masig Island, black line is line of best fit for a linear relationship, R^2 is 0.94.

4.4.2 Air Temperature

In general, daily average air temperatures are cooler than water temperatures. This reflects the greater range of air temperatures over a daily cycle and the fact that, even with this, it is warmer in the ocean than on land. Air and water temperatures for Madge Reef are shown in Figure 4.13. In general, the two follow each other although as expected the air temperature shows the greater range and extremes with a coolest of 23.3˚C for air temperature over 24.8˚C for water.

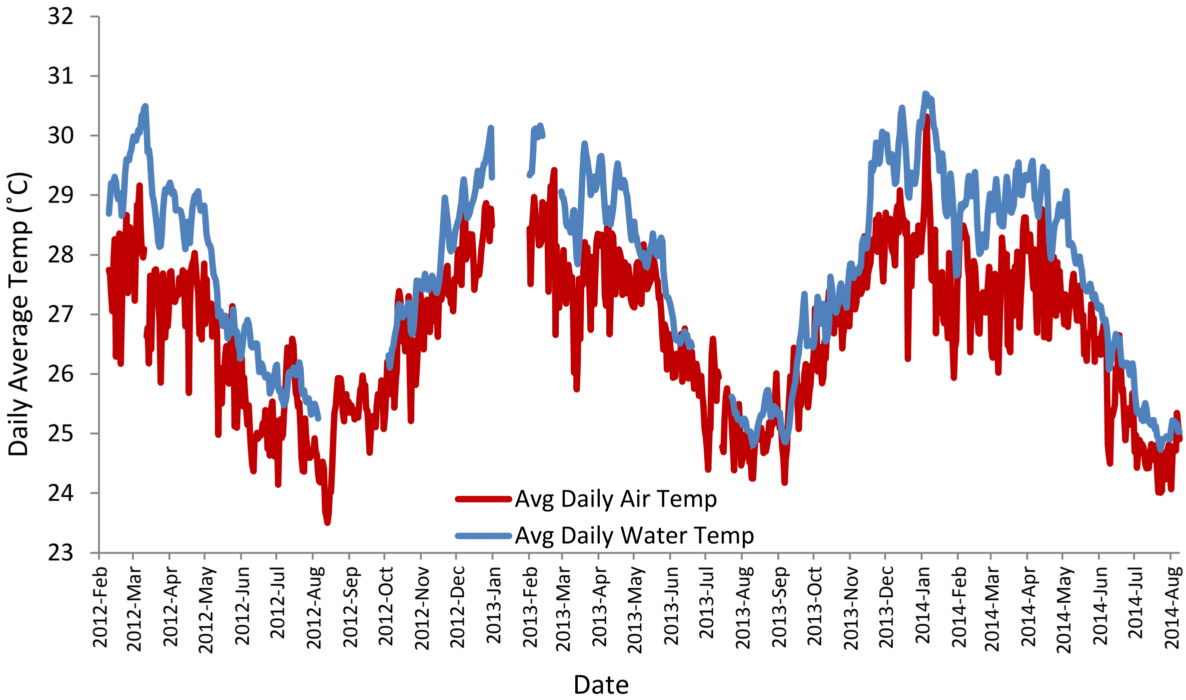

Figure. 4.13. Daily average air and water temperatures for Madge Reef (Thursday Island).

Examination of the differences between air and water temperatures (Fig. 4.14) shows a pronounced summer monsoon pattern with water temperatures around 1.5˚C warmer than the air versus around 0.5˚C in the winter.

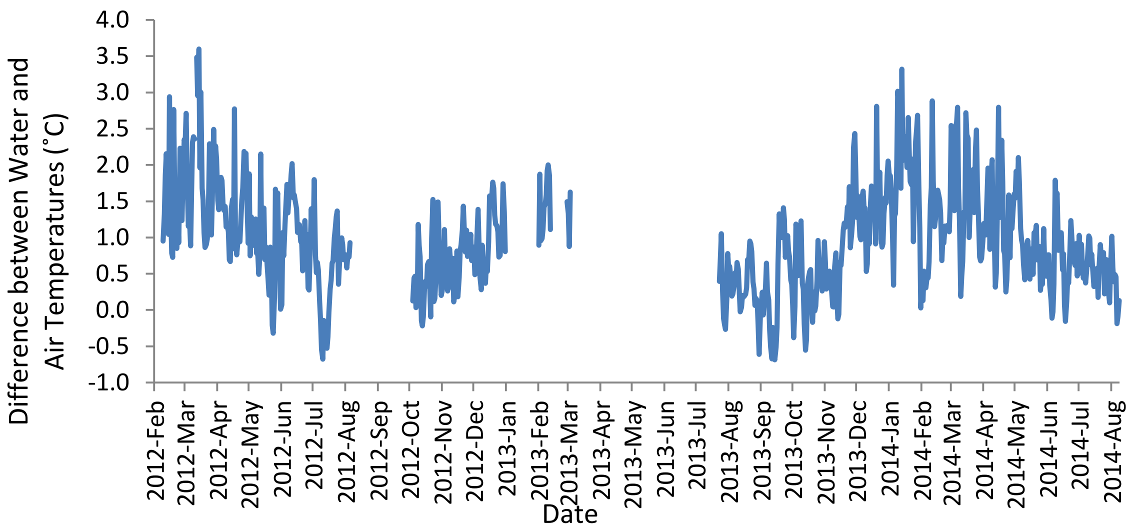

Figure. 4.14. Difference between air and water temperatures at Madge Reef (Thursday Island).

4.4.3 Wind

The wind data generally shows the expected pattern with strong south-easterlies dominating for the winter period to be replaced by north to north-westerlies during the monsoon season. Figure 4.15 shows the daily average minimum, maximum, and mean wind speeds (in kph) for Thursday Island overlaid with the wind direction (right hand axis).

The figure shows that winter periods are typified by winds from the South-East (average of about 120 degrees) at 25-30 kph (around 15 knots) while the monsoonal summer sees winds fluctuate more, tending North-West with wind speeds dropping to 10-15 kph (5-10 knots). The impact of the monsoon is dramatic with very sudden shifts from the winter South-East pattern (typically around late November) to the monsoon driven system and then back to the winter pattern (typically in late March).

The pattern at Masig Island Reef (Fig 4.16) is very similar with winter winds speeds around the 30 kph mark (15 knots) and summer winds around 10-15 kph. The summer monsoon includes periods of high wind (over 50 kph, 30 knots) and with changeable wind direction as the monsoon trough changes intensity. Note that this area is out of the tropical cyclone belt but can be influenced by doldrums conditions.

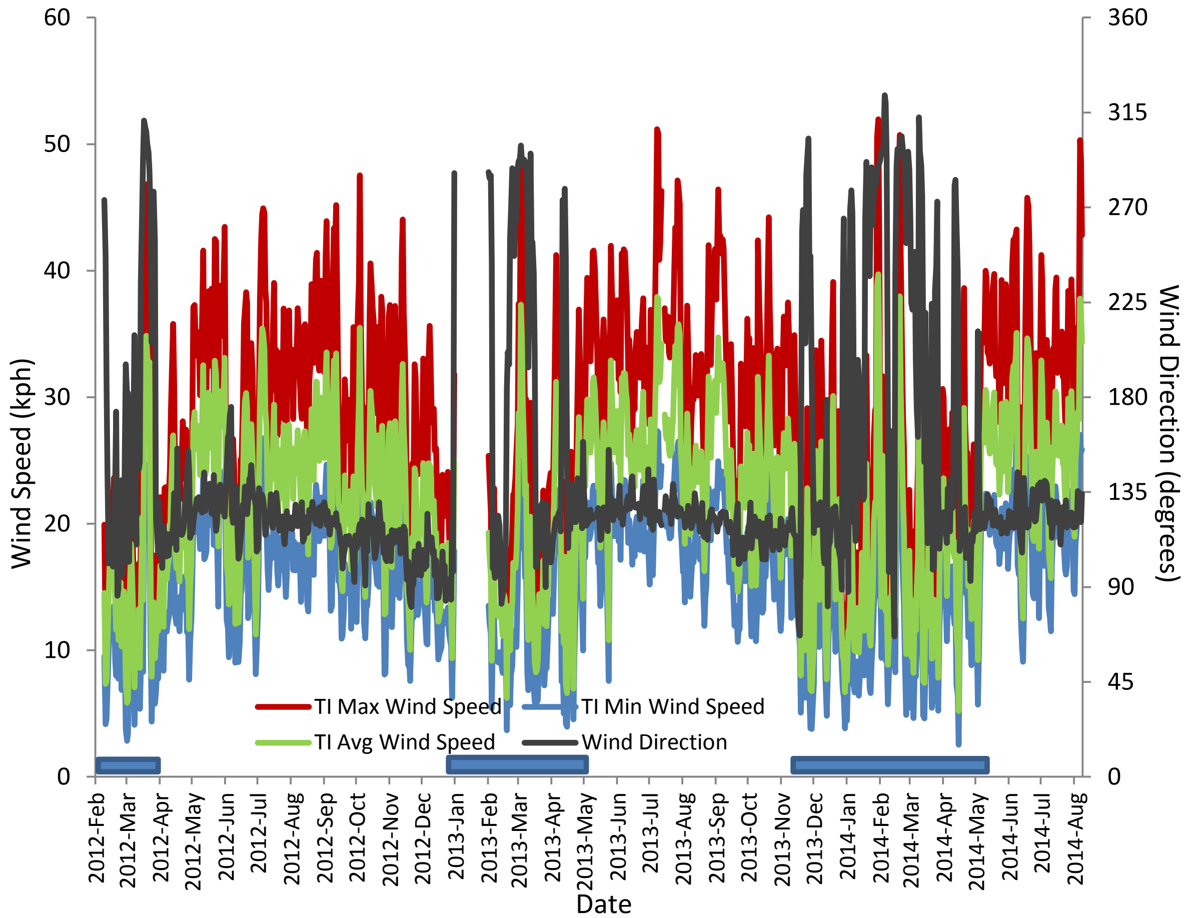

Figure 4.15. Wind data (speed and direction) for Madge Reef (Thursday Island) as daily min/max /average wind speeds, dark grey line is wind direction, blue bars show monsoon periods.

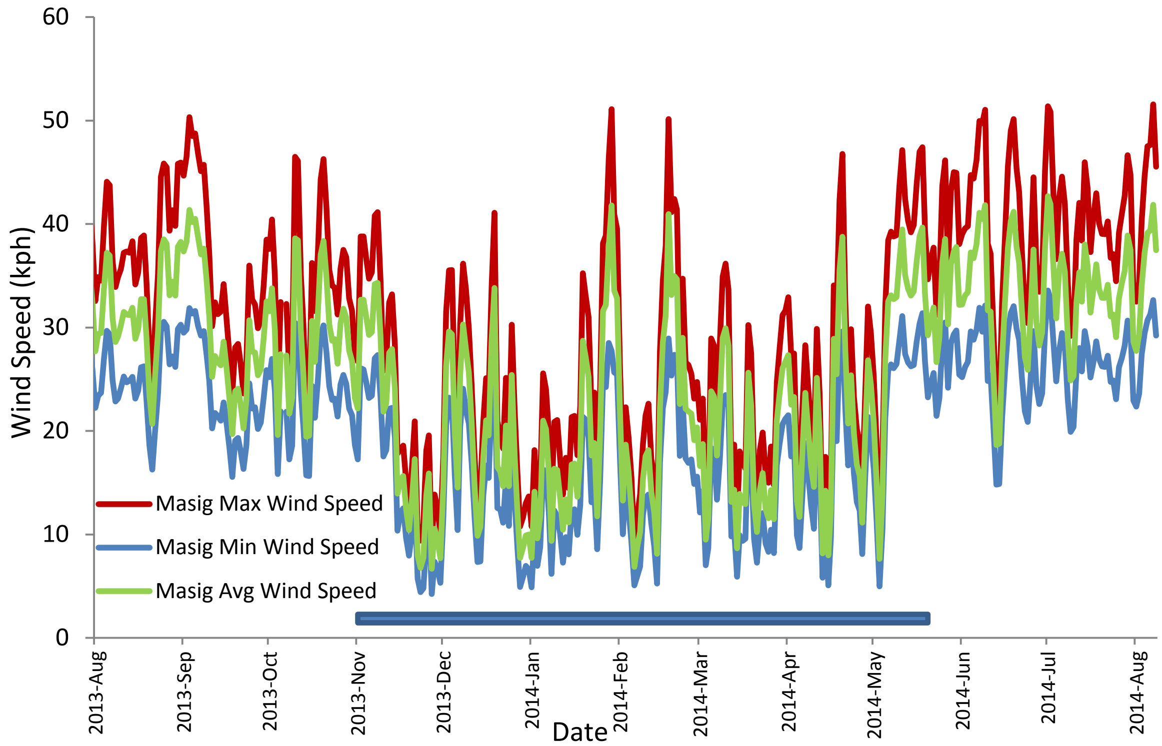

Figure. 4.16. Wind data for Masig Island, blue bar shows monsoon period.

The wind direction data for Thursday Island and Masig Island shows similar patterns (Fig. 4.17) with no effective lag between the monsoonal changes in wind direction at both sites. The graph of the difference in wind speeds between Thursday and Masig Islands shows that in general wind speeds are stronger in the north/north-east especially in winter, during summer wind speeds tend to be stronger at Thursday Island although this varies.

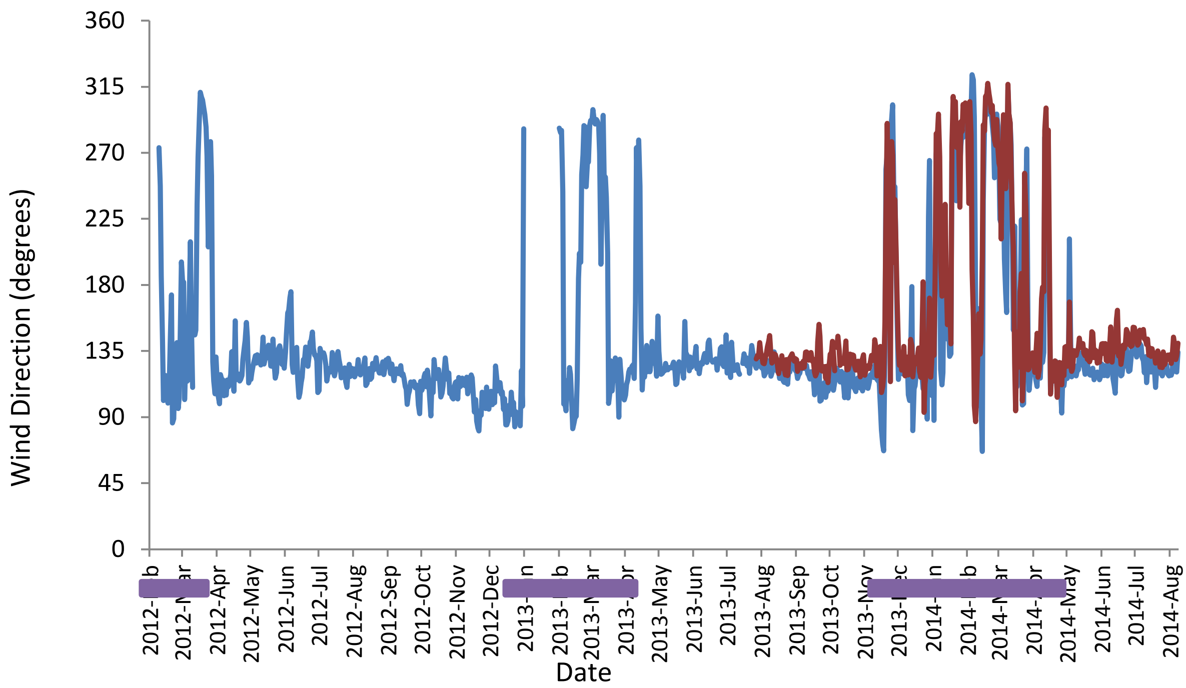

Figure. 4.17. Wind direction data for Thursday Island and Masig Island.

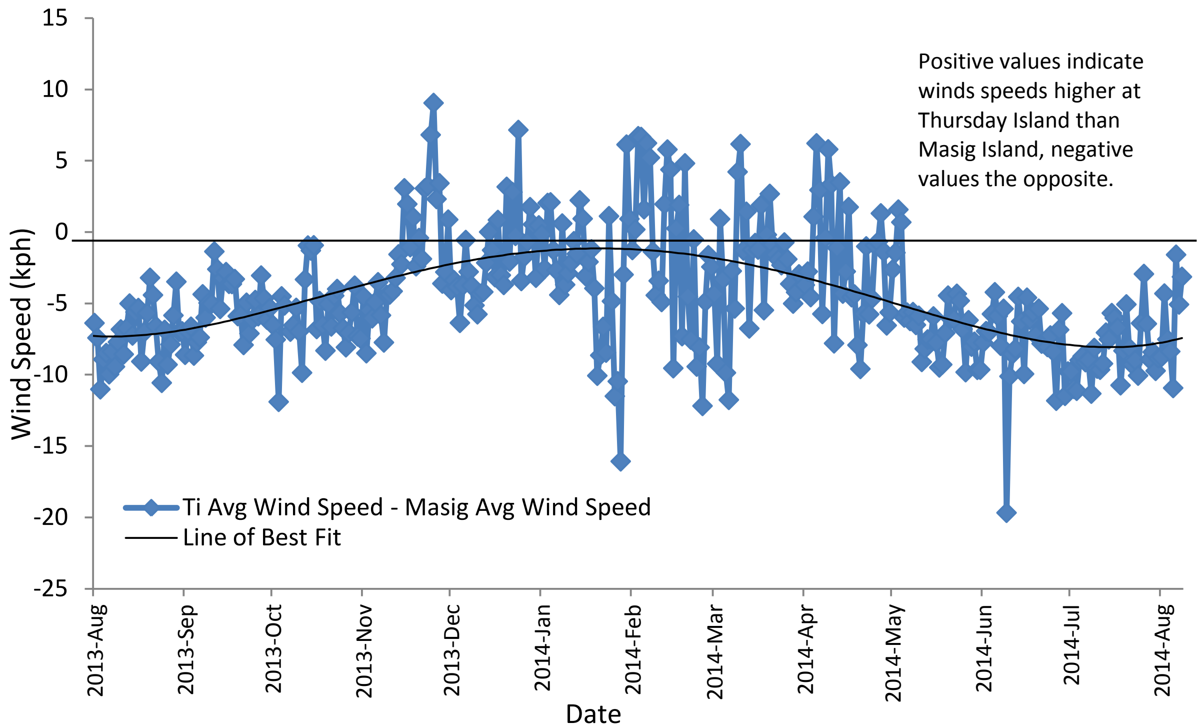

Figure 4.18. Differences in wind speed at Thursday and Masig Islands, positive values show stronger winds at Thursday Island with negative values indicating stronger winds at Masig Island.

4.4.4 Rainfall

Both Thursday and Masig Islands showed monsoonal patterns of rainfall (Fig. 4.19) with relatively dry winters and most of the rainfall being in summer. In 2012/13 at Thursday Island the first monsoonal rain was in late February, in 2013/14 there was more rain in November and December leading up to the main falls in late January.

In general Thursday Island gets more rain than Masig Island (for the year 01-Aug-2014 to 30-July-2014 Thursday Island received 2575 mm of rain, Masig Island 2150 mm) with daily maximums for Thursday Island of over 160 mm while the largest daily rainfall for Masig Island was around 120 mm. This difference may reflect the topography of the islands (Thursday Island is a high island) and their location in the TS. Note that rainfall around Thursday Island is very localised with nearby Horn Island often receiving less than Thursday Island.

4.5 Coral Bleaching

4.5.1 Bleaching Events

The temperature data showed that during the years that were monitored in-water temperatures did not get close to the known bleaching threshold and so there was no predicted or observed coral bleaching for 2012–2014. In general, due to global weather patterns, water temperatures were cooler or similar to the known long-term climatology and so the threat of coral bleaching for this period was low. As a result, while regular updates were issues during the summer periods no actual bleaching alerts were issued.

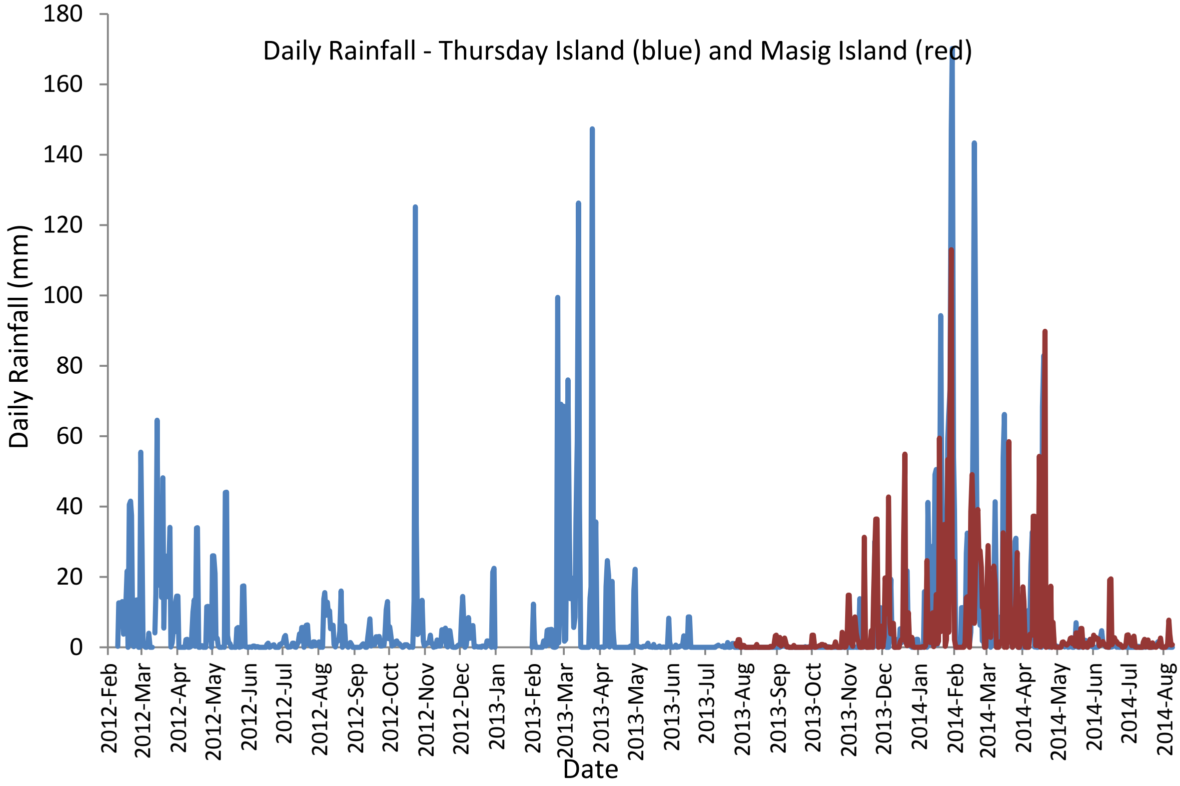

Figure. 4.19. Rainfall for Thursday Island (blue) and Masig Island (red).

4.5.2 Performance of the Bleaching Models

The bleaching alert system uses two Bayesian Models to identify the current and future risk of coral bleaching. Models were only developed for Thursday Island as this has the best historical data around which to build climatologies and bleaching thresholds. Given the relatively cool conditions the models reported only low levels of bleaching risk.

The modelled bleaching risk is shown in Figure 4.20 and super-imposed on the Thursday Island water temperatures as Figure 4.21. The index is a number scaled from 0 (no risk) to 1 (very high risk) reflecting the output of the model as determined from the real-time data inputs. Figure 4.20 shows that the bleaching risk was mostly very low only getting to 0.13 or low. The highest modelled risk was in late summer (March–May) with the lowest in winter in July–August.

Thursday Island shows that the model responds to temperatures exceeding the two Standard Deviation limits in March–May of each year reflecting a delayed cooling of water into winter for these years. As this is a time of warm water and high light the model identifies these temperature excursions over similar unusual water temperatures that occur later in the year but where the water temperatures are well below any bleaching threshold.

For the limited amount of data the models did seem to identify events that from the graph alone would indicate times of thermal stress even though the model seem to be less sensitive to these types of events that occur in the lead up to summer in November and December.

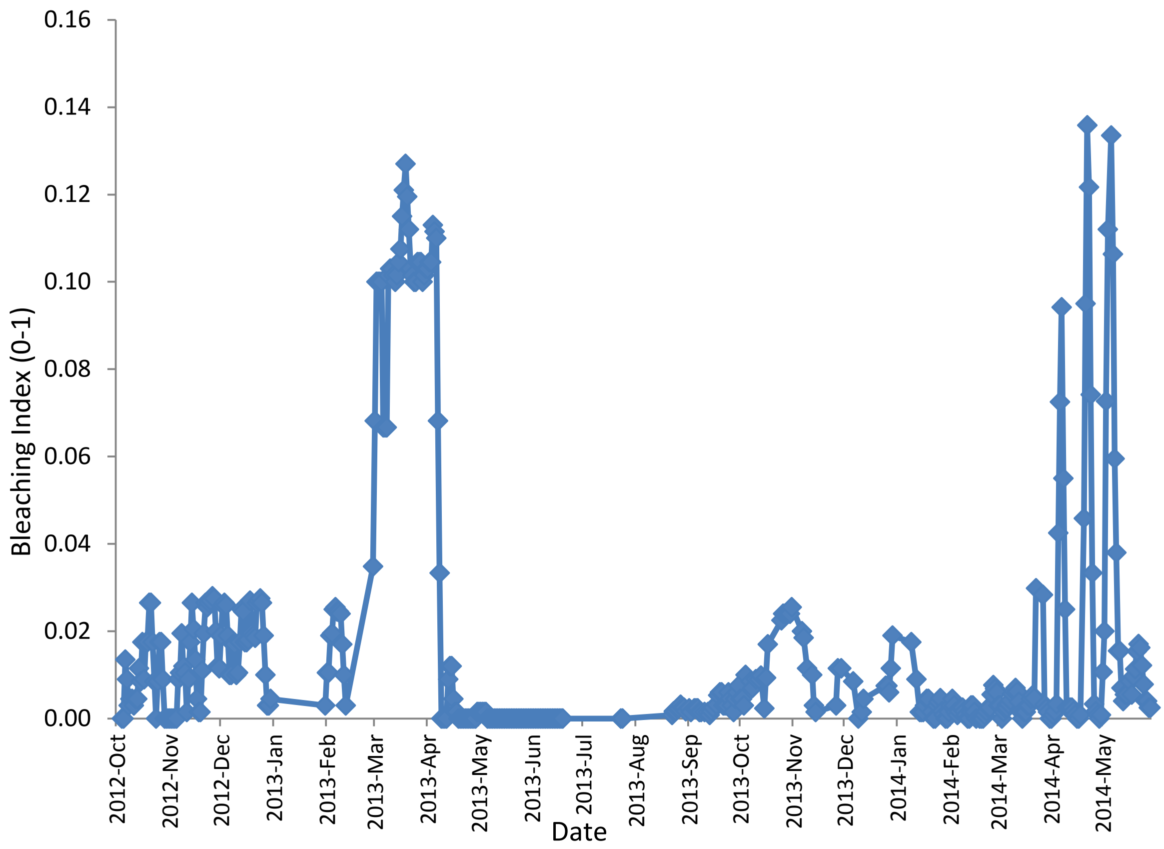

Figure. 4.20. Modelled Current Bleaching Risk index for Thursday Island.

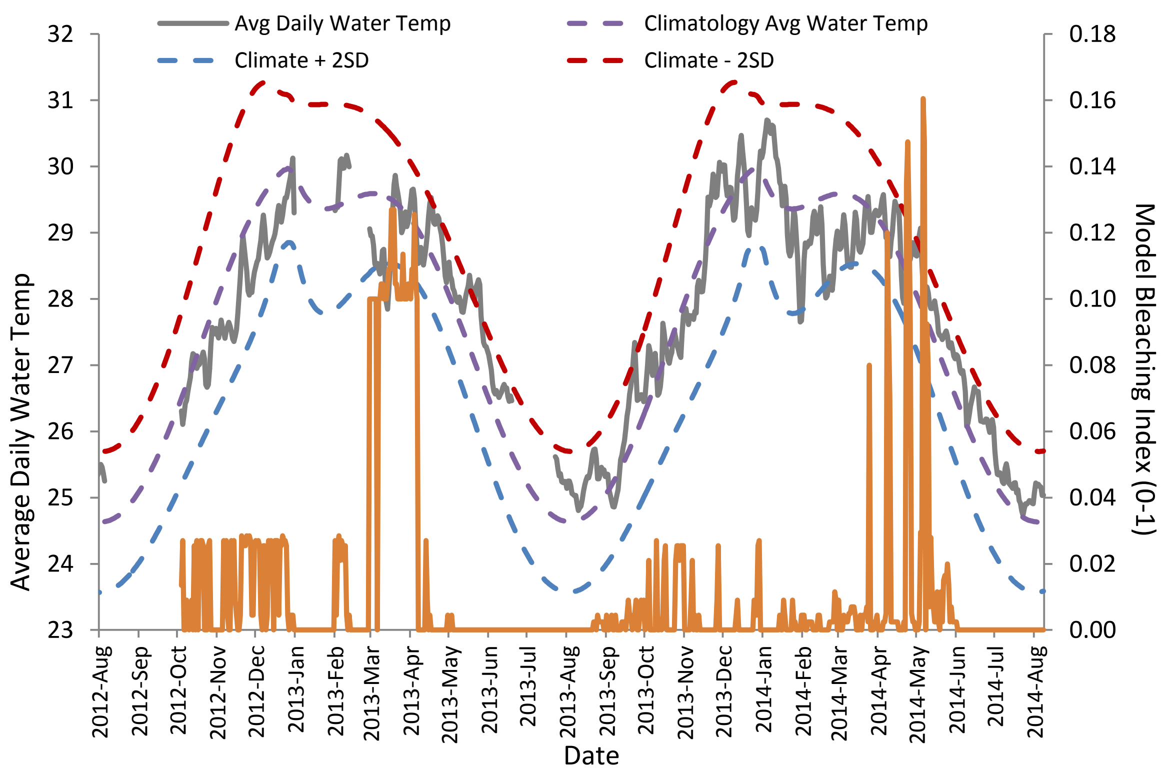

Figure. 4.21. Modelled Current Bleaching Risk index for Thursday Island overlaid on the water temperature/climatology graph.

The second model looked to forecast changes in bleaching risk in the coming two to three days. It does this by looking at factors that lead to temperature accumulation and dissipation in the water column as one way to predict how coral bleaching conditions and associated risk will change. Note that the predictive risk indicator is un-coupled from the current risk indicator, that is, the predictive model looks to identify periods of heat accumulation and dissipation independently of the current risk. For this reason it is not unexpected that the correlation between the two is weak.

If the predictive model works then it should indicate higher future risk before the current risk indicator changes although the lack of coupling between the two models means that this effect may be weak or complex. Figure 4.22 shows the two indices with the forecast index being between +5 (risk forecast to increase strongly) to 0 (no forecast change in the bleaching risk) to -5 (strong forecast decrease in bleaching risk). In general, the forecast model does go high when the current bleaching risk increases and for some events the forecast model goes high some days before the current risk model goes high indicating some ability of the forecast model to predict future changes in bleaching risk.

The models are still under development and while they show some ability to identify current and future risk there is more work needed to validate these and to extend them to other sites. It may be that coupled or linked current and future risk models perform better.

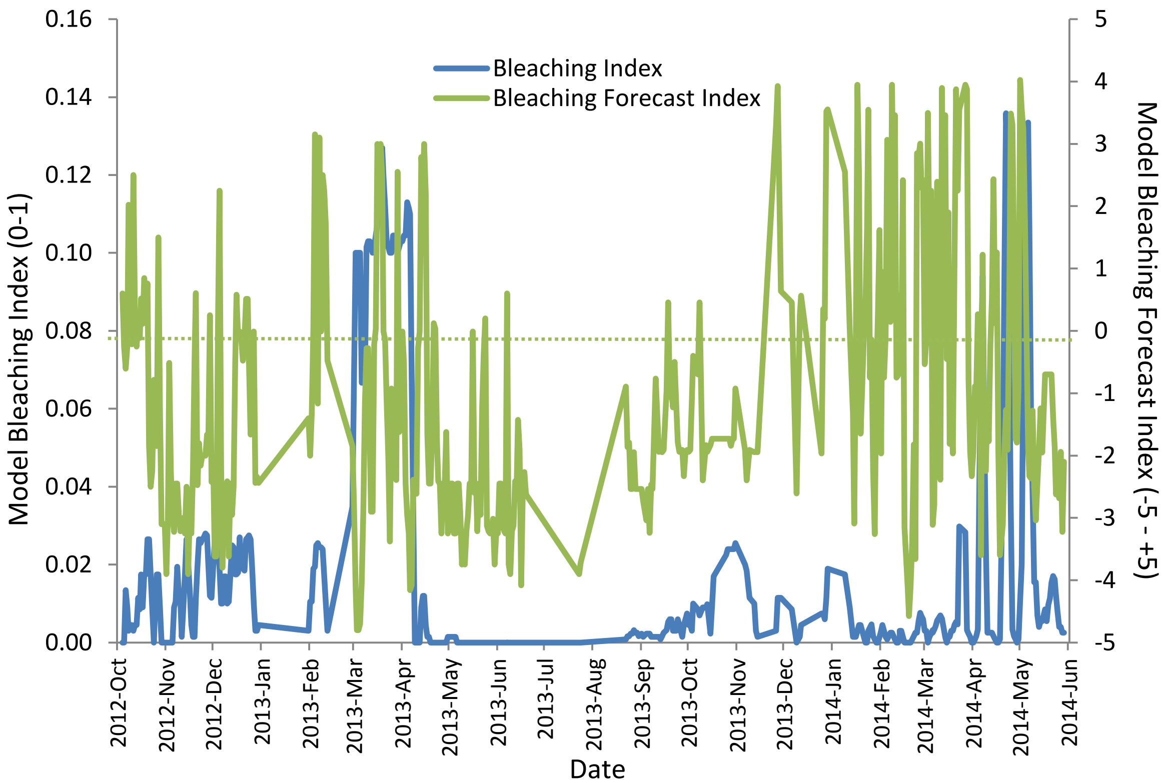

Figure. 4.22. Performance of the predicted coral bleaching risk model against the current bleaching risk model outputs.

4.6 Discussion

4.6.1 Coral Bleaching

The data from the real-time stations show that in general conditions were cooler than normal as measured against a 15-year climatology developed for Thursday Island. The data show that water temperatures rarely went over the three standard deviation limits that define extreme events, with maximum temperatures well below the empirical bleaching threshold for Thursday Island of around 31.4°C. While the historical data for the other sites is not as good, the relationship between the temperatures at the sites means that it is unlikely that temperatures that could cause coral bleaching were present at these sites or within the Torres Strait generally.

A consequence of the cooler than average conditions was that the models did not show any times when the risk of bleaching was high and no coral bleaching was observed in TS during this period. The cooler conditions are supported by the satellite data analyses and from the general conditions present in the western Pacific Ocean. Figure 4.23 (from Bureau of Meteorology 2014) shows the average surface temperature anomaly (difference between satellite measured ocean surface temperature and the long-term average) for the central Pacific which indicates that for the last few years temperatures have been below the average, indicating a La Niña weather pattern.

This is given greater context when compared to longer term patterns. Figure 4.24 shows NOAA data for the same index going back to the year 2000 showing the general La Niña conditions that have been present since 2010.

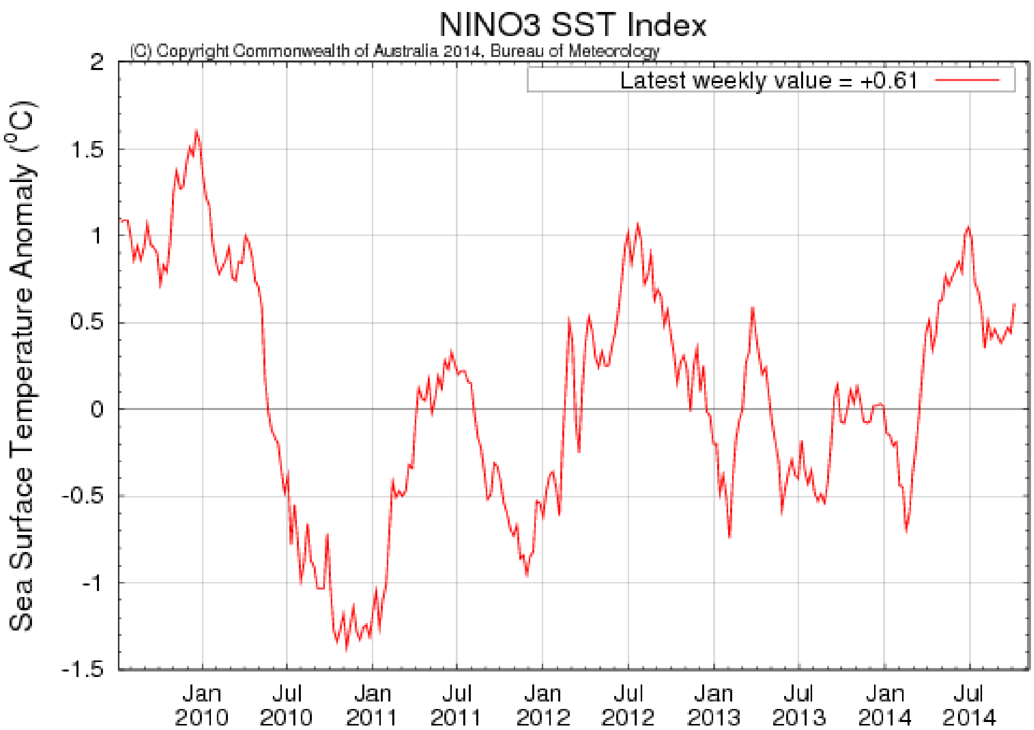

Figure. 4.23. Current Sea Surface Temperature Anomaly graph showing Pacific Ocean surface water temperatures as anomalies from the long term mean (source BoM, 2014).

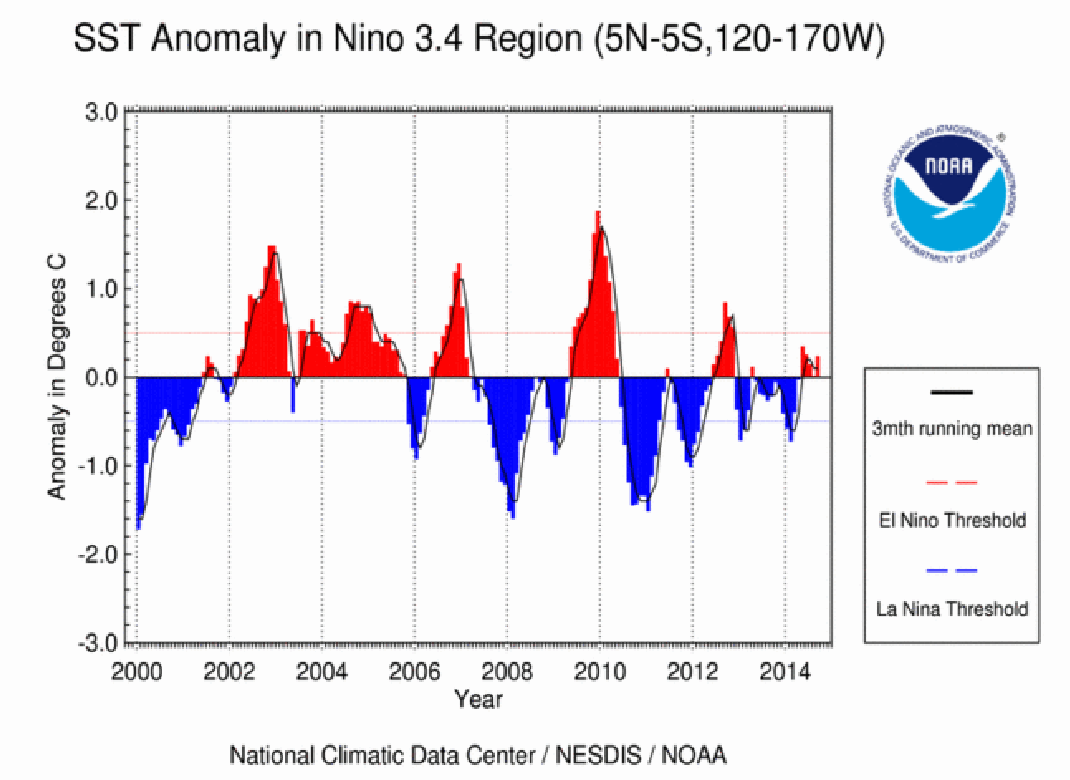

Figure. 4.24. Current Sea Surface Temperature Anomaly graph showing anomalies back to 2000 against the El Nino/La Nina thresholds.

It is possible to construct an anomaly graph for Thursday Island by taking the daily average water temperatures from the climatology; this can then be co-plotted with the BoM NINO3 Index used in Figures 4.23 and 4.24 to look for a relationship between Pacific Ocean patterns and those at Thursday Island. While the match (Fig. 4.25) is not strong there is a clear alignment, especially in the winter months. This may show the degree of connectivity between the Pacific Ocean and the Coral Sea and Torres Strait, especially in winter when the south-easterly winds may cause a greater connection to the east of TS.

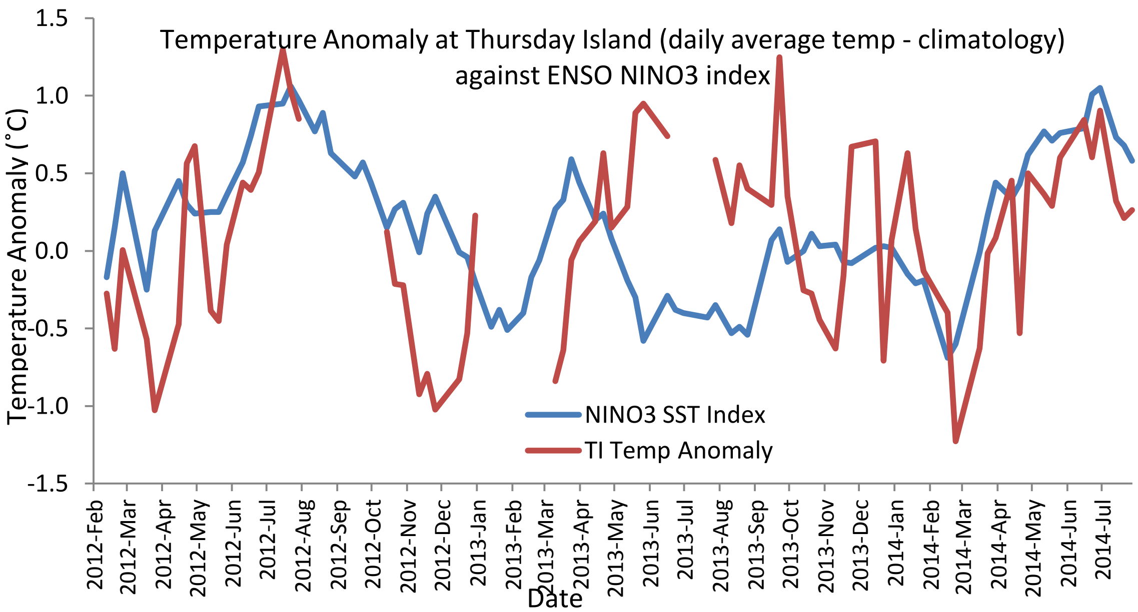

Figure. 4.25. Temperature Anomaly at Thursday Island against the ENSO NINO3 Index.

4.6.2 Weather Data

The weather data shows the highly monsoonal nature of the region with general dry winters dominated by strong south-east winds (consistently above 30 kph) and wet summers with winds coming from the north/north-west. The periods before and after the wet season have the greatest variability with wind direction and speed changing daily as the monsoon becomes established. Most of the rainfall is in the summer months until May with very little from June to November.

In general, conditions at Masig and Thursday Islands were similar although Thursday Island seemed to receive greater rainfall for the year where both stations were operating. Masig Island tends to be windier and warmer in the winter but Thursday Island is warmer in the summer. This may reflect the differing types of islands (Thursday Island is a high island while Masig Island is low) and their differing locations, with Masig being closer to the equator. There may also be timing differences with monsoonal weather patterns due to differing latitudes.

4.6.3 Uptake and use of the data

One unforeseen but positive outcome from this project has been the large community interest in the real-time data, especially the weather data. This relates to the lack of official weather stations in the Torres Strait with there being only two – Horn Island and Poruma Island. The station at Horn Island is inland near the airport so often provides readings that don't reflect actual on-water conditions. The station at Poruma Island has become protected by vegetation and shifting sand so that the wind readings are now half of what would be expected. This is known by BoM and will be rectified but means that the NERP stations represent the only true weather stations in the entire Torres Strait at this time.

To ensure that local communities gain access to the real-time weather station data the project has installed data kiosks in the local radio station (iPad based system), a general store on Thursday Island (Col Jones) and in the council building on Masig Island. General purpose websites are also available.

The value of the real-time weather data shows that there is a need to continue the work and it shows the ability of the local communities to utilise and uptake data that is being collected for scientific purposes as long as it is well presented and communicated. This additional value is an essential outcome of the project and shows that there is an existing high level of community understanding and engagement with the work being undertaken.

4.6.4 Climatologies, Bleaching Risk Models and Management Responses

The value of the climatology developed for Thursday Island is that it allows for a simple definition of 'normal', 'unusual' and 'extreme' temperature events to be developed that can be directly linked to appropriate responses. The climatology gives context to the daily real-time data and allows models and alerting systems to distinguish between events that are actually of concern versus those that are not.

The two bleaching models attempt to distil the relationships between those factors known to contribute or influence coral bleaching and the current data. This effectively encapsulates the 'expertise' of the scientific community into a single system that can provide numerical probabilities of coral bleaching given the input conditions. While these are far from perfect the use of Bayesian Models allows for 'fuzzy' relationships, for uncertainty in measurements and for other inputs such as local knowledge to be incorporated. The models require further development but provide a simple framework for people to understand and have input into how bleaching risk might be calculated at a given point in time.

The relatively cool conditions during the study period meant that it was not possible to validate the models against real world observed bleaching and so there is further work to try and validate these as conditions allow. There is also a need to construct these for other sites in TS, either through the collection of more baseline data or by trying to transfer the work at Thursday Island across to the other sites.

The models provide a clear concise index of current and future risk which can be directly linked to management responses and so it becomes possible to construct a response matrix given a number of risk scenarios. The systems therefore provide the types of inputs that can be integrated into management responses and provide an important source of information about current and possible future bleaching outcomes.

4.6.5 Future Work

The current forecasts of longer term trends in the Pacific Ocean show that conditions may return to El Niño patterns in late 2014 and if this persists then it will lead to higher than normal temperature patterns and increased coral bleaching risk. This means that the real-time stations and bleaching models will be an important part of understanding what is happening and in being able to respond to a potential bleaching event. This puts more focus back on getting all stations fully operational, including the one at Maizab Kaur, and in validating the bleaching risk models. It also emphasizes the need to develop appropriate responses to any forecast or observed bleaching and so linkages between the observational and management systems need to be explored.

The large uptake in the weather and ocean data by the local communities highlights both the current lack of good local data and the dependence on this data for much of the marine operations that form a large part of daily life in the Torres Strait. There is a need to continue to provide this information, to continue to find new ways to communicate this such as via weather apps, local data displays and traditional methods such as radio and television. If possible, it would be of value to expand the network of stations to include other areas so as to support these communities and to provide a better picture of overall patterns across the Torres Strait.

The stations have provided a valuable infrastructure for other projects with the station at Maizab Kaur being a good example where three differing projects are utilising the same infrastructure; Fly River monitoring, turtle and seabird monitoring utilising the real-time station systems. These types of synergies reduce the cost of working in this region and help to fill the many observational gaps that exist in both the marine and atmospheric areas. The transition of the current systems into multi-purpose observational platforms would increase the return to the scientific and local communities for the investment committed.

The final link is the provision of data to support other studies. There is a growing need to understand marine influences in the region, weather from outflows of major rivers, potential impacts of spills or factors influencing the breeding success of turtles, seabirds and dugongs. All of these rely on basic oceanography and the data being collected by this project is providing some fundamental information that is required to understand the complex oceanography of the region. Future work may focus on integrating this data with modelling work, and in collecting data for identified gaps to validate and extend the modelling and oceanographic work.

4.7 Conclusion

The project has overcome logistical, weather and other obstacles to successfully install three real-time stations in the Torres Strait. The success of the initial stations has led to the partial funding of one additional station (Masig Island) and substantial funding of a third station (Maizab Kaur). This shows the value of this type of data to TSRA and, via the data outreach, to the local communities.

The project has used leading edge data and information techniques, such as Bayesian Models and in-house programs, to build a series of information systems that deliver measures of current and forecast bleaching risk that can be directly linked to management outcomes. This delivers against the initial goals and builds a solid base for continued work in the region.

The years that have been sampled have been cooler than normal and so no coral bleaching was predicted or observed. While this is good news, the current satellite data shows that this cool La Niña period may be coming to an end with current conditions neutral but many forecasts looking at the system going into an El Niño phase in the next year. If this occurs then conditions may again increase the risk of coral bleaching and so the system that are in place may become critical in early warning of coral bleaching and in being able to initiate management responses where appropriate.

4.8 Publications

There has been one publication from this work:

Bainbridge, S. and R. Berkelmans (2014) The use of climatologies and Bayesian models to link observations to outcomes; an example from the Torres Strait. Environmental Science: Processes & Impacts, 16(5): 1041-1049.

Appendix 1

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Coral Reef Monitoring Program for the Torres Strait: Workshop Report

Workshop Report and Recommendations for Coral Reef Monitoring in the Torres Strait
NERP Project 2.3: Monitoring the Health of Torres Strait Coral Reefs

November 2014

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Confidentiality

This document has been prepared as a report of the workshop held at AIMS on the 9 October 2014 to develop the basis for a coral reef monitoring program for the Torres Strait as an outcome for Project 2.3 under the NERP Tropical Ecosystems Hub and is provided for the sole purpose of reporting for this project. This report is based on an **EXPOSURE DRAFT** and so may contain material that is revised or omitted in future versions and which has not been reviewed by the partner organisations.

Document Control

Version	Date submitted	Prepared by	Reviewed by	Date of Review
Exposure Draft	28-Nov-2014	Scott Bainbridge	AIMS / TSRA / CSIRO / RRRC	Jan-2015
Final Report	20-Jan-2015	Scott Bainbridge	-	-

Contents

Executive Summary

The coral reef monitoring workshop held at AIMS in October 2014 was part of a NERP funded project to assess and monitor the health of reefs in the Torres Strait. As part of this project, an initial suite of reefs were surveyed and the expertise to continue these was transferred to the Land and Sea Management Unit (LSMU) of the Torres Strait Regional Authority (TSRA). In the broader context, Torres Strait reef monitoring complements longer-term monitoring in the Great Barrier Reef (GBR) to the south that has documented a 50% decline in coral over 27 years of monitoring [3] and where issues such as climate change, coral bleaching and crown-of-thorns starfish outbreaks pose a threat to all reefs including those in the Torres Strait.

The outcomes from the workshop have been used to inform the development of an integrated monitoring and response plan that will be presented in early 2015 as part of the NERP project reporting. This plan will be used to develop operational level plans for the initial monitoring and then to develop a longer term framework and plan for sustained monitoring linked to defined management responses.

Workshop Outcomes

Preamble: Goal of the Torres Strait Coral Monitoring Program

At the start of the workshop there was a discussion about the overall goals of coral reef monitoring in the Torres Strait, with the main ones listed below:

1. To set a baseline in order to estimate and measure change. While there have been a lot of previous studies, these data had not been collected specifically to provide a system-wide comparable baseline for future work.
2. To identify events of interest or concern such as coral bleaching, Crown-of-Thorns Starfish (COTS) outbreaks, coral disease, changes in fish populations and so on. The long-term intent is to link results from the monitoring to management responses and activities to best ensure the sustainability of Torres Strait reefs.
3. To support the sustainable use of a range of resources from commercial species (mostly already captured under existing monitoring programs) and local subsistence fishing including identifying high value areas, trends in population numbers and so on.
4. To more effectively link observations and issues from the people who live and work in the local marine environment with the higher level TSRA goals.

Session 1: Current and Past Monitoring of Reef Resources in Torres Strait

Marine Resource Surveys: CSIRO

CSIRO have been conducting reef surveys, mostly in the western part of the Torres Strait, since 1995 as a way of assessing fish, tropical rock lobster and beche-de-mer stocks. The initial sampling program [1] including some 1,247 sites sampled in 1995 with 20m x 2m belt transects being located on the tops of 43 reefs for a total of 374 sites. Transects were scored for percent cover of sand, rubble, live coral, boulders as well as the percent cover of the dominant sessile flora and fauna. Separate counts were done for holothurians, giant clams, pearl shells and other large gastropods.

As part of this on-going work the project has identified the following changes:

- A decline in hard coral cover from 2002 to 2009 although coral cover in the western reefs is low so the significance of this decline is uncertain.
- A significant crown-of-thorns starfish (COTS) outbreak observed with an increase in density of starfish from 2002 to 2009 and an active outbreak in 2009 with an estimated 900,000 starfish on some reef areas (notably Dungeness Reef).
- COTS densities in the outbreak were around nine per hectare which is above the modelled sustainable density of five per hectare indicating that the coral cover on these reefs may decline due to COTS activity.
- The bleaching event of 2010 was seen in the western reefs sampled with approximately 20% of the western reefs sampled showing some degree of bleaching.

- The recent surveys in 2011 however showed a recovery in hard coral cover showing little long term impact from the 2010 bleaching event for those reefs sampled although the reefs in the area have a low coral cover so it may be hard to pick up changes in coral cover.
- That sea grass cover has increased and this seems to be correlated with an increase in the abundance of tropical rock lobster.

CSIRO also monitor the large commercial fisheries in the Torres Strait including Tropical Rock Lobster, mackerel and beche-de-mer. Their work also showed that local fin fish are a very important resource to the local people and the access and sustainability of this is of high importance.

Reef Monitoring: AIMS

Under the NERP program a series of biodiversity surveys have been done at five reefs in the eastern to central Torres Strait, the outcomes from the surveys are presented as a technical report [2]. The work comes from similar programs run in the Great Barrier Reef (GBR) that show a 27 year decline in coral cover for the GBR although most of this decline has been in the southern and central regions of the GBR due to the impact of COTS, storms, bleaching and coastal run-off [3].

The surveys done under the NEPR project found:

- The reefs in the eastern part of the Torres Strait are diverse (296 species of coral, 301 species of fish) with the surveys finding species new to the Torres Strait and some new to Australia.
- The reefs are generally in good condition with little evidence of large scale disturbance.
- There may be a small decline in some temperature sensitive species at some sites and some coral disease and crown-of-thorns starfish were recorded.

Issues Raised / Outcomes from this Session:

A number of issues were raised in this session:

- Differing methods used by the CSIRO and AIMS surveys, how to reconcile this to give a larger pool of comparable data.
- CISRO surveys mostly the western and central reefs leaving the eastern reefs largely un-monitored although the AIMS surveys under NERP have filled this gap but using differing methodology and with uncertain future effort.
- The importance of monitoring local fin-fish species as these have a high importance to local people along with the main commercial species.
- Need to survey some areas annually to pick up changes or to get early warning of potential impacts, may need to have layered monitoring plan with some reefs surveyed annually and others less regularly.
- Need to better communicate some survey outcomes, such as bleaching and COTS events, and to link these into higher level responses.

Session 2: The Torres Strait long-term coral reef monitoring program

Torres Strait Coral Reef Response Plan

The C_2O group has been tasked with developing a Torres Strait Coral Reef Response Plan, which will be coordinated by Johanna Johnson.

Johanna presented the following points for discussion:

- The need to incorporate community input.
- Undertake a desktop study to synthesise existing work with communities to identify high value areas and important species (not necessarily monetary, but subsistence) to assist in the development and focus of the monitoring strategy.
- The need to start small, not overstretching resources and commitment, and build up capacity and expand monitoring program when feasible.
- No need to get caught up in the logistics of monitoring, the community monitoring and opportunistic ranger surveys can be undertaken from the shoreline.

Monitoring Plan Discussion

A general discussion about what parameters, locations and methods could be used was held with the following outcomes.

Monitoring location discussion:

- CSIRO covers with their biannual monitoring (June and November) much of the western and central clusters of islands and undertakes habitat and fisheries species monitoring.
- The current gaps in their biannual surveys are the Eastern Cluster Islands.
- There is currently no funding for future AIMS surveys in the eastern parts of the Torres Strait (but maybe under NESP).
- Given available resources and current capacity it was agreed that coral reefs adjacent to communities be monitored initially including Ugar, Erub, Mer, Masig and Poruma.
- CSIRO has conducted surveys on each of these reefs on two previous occasions and will give the waypoints of each to assist in site selection at each reef.
- As capacity increases and resources become available these sites may be increased.

Monitoring dates:

- Johanna Johnson suggested that in order to capture any impacts of run off and increased temperatures (e.g. bleaching, disease, COTS) monitoring should take place around March each year.
- CSIRO currently undertakes monitoring in June and November each year, with November noted as a good weather period and June noted as a bad weather period for monitoring.

- Currently the TSRA undertakes annual Nesting Marine Turtle Surveys at Dauar during the last two weeks on November each year.
- In order to potentially pool resources for monitoring, CSIRO is willing to move their November surveys to the start of the month to accommodate this clash.
- It was realised that the next surveys will remain unchanged and occur in March 2015, but future surveys are recommended to be undertaken annually at the start of November to increase the chances of monitoring in good weather.
- A concern was raised that annual monitoring might not be sufficient to maintain the skills developed by rangers to undertake the monitoring, it was recommended that monitoring should be undertaken biannually in order to ensure the skills are not lost.
- Once monitoring sites are established in March 2015, monitoring may be able to be undertaken in March and November each year by use of ranger vessels and TSRA LSMU staff.

Method discussion:

- The current AIMS, GBRMPA methods were discussed against current TSRA capacity and resources, snorkel qualified TSRA LSMU staff members have been trained in the GBRMPA RHIS methods and AIMS manta tow methods.
- It was mutually decided that initially three methods would be used by the TSRA for the long-term coral reef monitoring: reef health and impact survey, underwater visual census and manta-tow methods.

GBRMPA Reef Health and Impact Survey (RHIS):

- The RHIS method [5] will be used to quantify benthic percentage composition, incidence of threats/impacts and trends over time.
- Four (4) sites per location (four quadrats of the reef), with three (3) replicates per site.
- RHIS replicates will be placed 50 m apart, parallel to the reef slope.
- Due to low replication, RHIS replicate sites will be permanent, marked by using a star-picket to identify the RHIS centre point.
- Photos of each replicate's benthic substrate will be taken and stored to assist comparison and analysis of long-term changes.
- See RHIS survey sheet for specific data that will be recorded.

Underwater Visual Census Survey – Fisheries and Threat Species:

- The UVC method [6] will be used to record the relative abundance and density of target fishery and threat species.
- It will be conducted for a length of 100 m, measured by use of the spaced RHIS sites (i.e. distance between 3 sites = 100 m).
- There will be two personnel recording data, the first will record key fishery species on a 5 m wide belt (e.g. coral trout, giant clam, etc.), the second will record benthic/cryptic species on a 2 m wide belt (e.g. COTS, sea cucumbers).

- A photo of the substrate will be taken every 5 m using a digital camera, which will assist in long-term status trend analysis.

Manta-Tow Survey:

- It was noted that the manta-tow survey method [7] was not suitable during poor visibility or rough conditions as the data may be incomplete or inaccurately collected.
- It was suggested that the manta-tow method be used in the TSRA long-term coral reef monitoring strategy to maintain ranger skills, as this method is effective for larger scale surveys such as for identifying the spatial extent of various impacts/threats as part of the management response plan (e.g. bleaching, COTS).
- Note: The large reef size of some islands (e.g. Erub's fringing reef) will need to be considered as it may not be realistic to manta-tow around the entire island.

Issues Raised / Outcomes from this Session:

- Given the available resources and current capacity it was agreed that coral reefs adjacent to communities will be monitored initially, including Ugar, Erub, Mer, Masig and Poruma. As capacity increases and resources become available the number of sites may increase. It was also recommended that monitoring should be undertaken biannually in order to maintain ranger skills.
- In order to capture any impacts of run off and increased temperatures (e.g. bleaching, disease, COTS outbreaks) monitoring should take place in March each year. Once monitoring sites are established in March 2015, monitoring may be able to be undertaken in March and November each year by use of ranger vessels and TSRA LSMU staff.
- Initially three methods would be used by the TSRA for long-term coral reef monitoring: (i) reef health and impact survey, (ii) underwater visual census, and (iii) manta-tow methods.
- The RHIS method would be used to quantify benthic percentage composition, incidence of threats/impacts and trends over time.
- The Underwater Visual Census (UVC) method will be used to record the relative abundance and density of target fishery and threatened species.
- The manta-tow method will be used to maintain and further develop ranger skills and to identifying the spatial extent of various impacts/threats to inform the Coral Reef Response Plan (e.g. bleaching, COTS outbreaks).

Session 3: Management responsibility options for the TSRA and other stakeholders

Management Response – Threat/Impact Identification:

There is a recognised need to be able to link management outcomes and responses to the results of reef monitoring. This includes the ability to undertake reactive surveys for events such as coral bleaching and COTS outbreaks. The recent report of increased COTS observed and reported by CSIRO demonstrated that the TSRA does not currently have the operational capacity to respond to incident reports.

In the future, if a report of a COTS outbreak or bleaching event occurs it was recommended that a monitoring team be deployed to conduct comprehensive surveys, including:

- Minimum of 10 RHIS sites each with 3 replicates.
- Starting where the report was made and expanding out concentrically.
- Also adjacent reefs need to be checked, if they exist.

It was discussed that the TSRA does not have any decision-making powers regarding management decisions, and any management decisions would need to be made by respective RNTBC's, including the Malu Lamar (Torres Strait sea claim RNTBC).

The following process was discussed:

- The TSRA collaborate with Malu Lamar and respective RNTBCs to agree on a response (i.e. comprehensive survey) to verify and quantify reported threat/impact.
- The TSRA deploy a qualified monitoring team to undertake comprehensive RHIS surveys and manta-tow surveys at the reported location.
- The TSRA collaborate with expertise (e.g. AIMS, CSIRO, GBRMPA) to discuss outcomes and brainstorm recommendations (currently TSRA does not have the capacity/experience in management recommendations; this process will assist in developing those skills).
- The TSRA will present outcomes and recommendations to the Malu Lamar/RNTBC/TSRA Board for a decision on how they would like to proceed.

Issues Raised / Outcomes from this Session:

- Currently there are few resources to respond to any events, such as coral bleaching or COTS outbreaks, identified through the reef monitoring, and a proposed process was discussed.
- It is anticipated that these discussions will inform the Coral Reef Response Plan and form a basis for future management responses.

Session 4: Future research priorities

The final session was to be based around future priorities but with the arrival of participants from GBRMPA it was decided to focus on their program of monitoring and environmental assessments and in particular on the RHIS methodology.

The GBRMPA participants gave a presentation on the RHIS methodology, the data systems that support this (including a web dash-board) and the 'Eye on the Reef' program, including the online App. There was a discussion about the use of the RHIS method and how it is used in the GBR to look at health trends, storm damage and COTS outbreaks.

The discussion then centred on data collection and data management with the following discussed:

- The GBRMPA 'Eye on the Reef' system [8] and App could be used in Torres Strait although they may need some additional base maps (such as from the eAtlas [4]).
- The RHIS database is managed by GBRMPA along with the basic reporting tools, this could be made available to the TSRA, again with the need for base maps, either as is or maybe as a dedicated sub-site within the RHIS system.
- The manta-tow database is managed by AIMS and can be made available to the TSRA along with data entry and checking systems.
- The only method without a dedicated data management system is the Underwater Visual Census work so this may require some work to develop an equivalent system.
- It was noted that any data management system needed to be built on proven database technologies rather than spreadsheets or other ad-hoc systems, given that systems already exist for some components it is important to put in place best practice for any new work.

Issues Raised / Outcomes from this Session:

- It was understood that data management is a key part of any monitoring system and so this component needs to be developed in parallel to the physical monitoring work.
- There are a number of data management systems in place to support the proposed monitoring work; some of these may be adaptable to the Torres Strait with the provision of applicable base maps.
- For the RHIS and manta-tow methods, the data systems exist in differing organisations which may cause issues, for the UVC method there are no easily accessible data management systems.

Post amble: Discussion Gaps

While there was a good level of discussion around the immediate needs and opportunities there were a number of items that were not explicitly discussed and which need to be considered in subsequent planning.

These include:

- A breakdown of the higher-level monitoring goals to define exactly what the monitoring should achieve, this will inform the process of developing a robust experimental design and in understanding and setting the statistical power of the monitoring program. This is not a trivial issue but there is considerable expertise and lessons learnt from the GBR.
- The resources and need for proper data management, while this was raised just how this would be implemented and sustained remains uncertain.
- The use of the baseline Line Transect data, especially as a tool for detecting smaller scale change over time.
- The long-term sustainability of any program in terms of funding, personnel, resources, expertise, logistics, and training, including the relationship between the program and the main research agencies and the ownership of any resulting program by the TSRA and other local agencies.
- The nature of linkages to responses and actions if major change is detected, this is being investigated but requires an alignment of responsibility and authority, especially with regard to liaising with Malu Lamar and in implementing responses.
- The acknowledged artificial divide between the GBR and the Torres Strait and how this can be removed to encourage much of the base science and monitoring work, resources and expertise currently deployed in the GBR to naturally flow to the Torres Strait (for example, the concept of using the Torres Strait as a natural climate change laboratory to contrast and compare with GBR reefs).
- The lack of some base science in the region, such as ocean observing, that will allow an understanding of why systems are changing rather just detecting that they have changed.
- How any monitoring would work within other marine issues in the Torres Strait including shipping, impacts from PNG and so on.

Many of these items are non-trivial and outside the scope of both the workshop and the NERP funded projects but may be critical in ensuring that the work done so far can be the foundation for sustainable long-term projects in the region.

Workshop Recommendations

Monitoring of Torres Strait reefs needs to meet management and community goals, this purpose sets the type of monitoring, the frequency, site locations and the methods used. The recommendation is that a series of monitoring methods or components are required to address particular issues and these will utilise a variety of methods at a variety of locations. The challenge then is to ensure that the results and outcomes of each monitoring component inform the other components and that an overall larger picture is maintained to put in context the results from the individual components.

The following set of monitoring components is proposed:

Component One: Community Monitoring for unusual events or events of interest

Question:	**Are there unusual or note-worthy things happening on reefs that are visited by local communities?**
Rationale:	There is a need to document events of interest that occur throughout the Torres Strait using the local communities. Isolated incidents may not mean much individually but may reflect wider issues. Examples include large numbers of crown-of-thorns starfish, coral disease, coral bleaching, turtle and dugong deaths, seabird deaths, fish kills, marine pollution, illegal fishing, etc. By building up a comprehensive database of information it becomes possible to identify potential issues before they become widespread or to gain an understanding of emerging issues that need to be addressed by future policy and management actions.
Proposed Solution:	The GBRMPA 'Eye on the Reef' reporting program and associated systems (phone App's, website, reporting mechanisms) could be adopted and extended into the Torres Strait with some expansion of the system to cover issues relevant to the TS.
Location:	As the monitoring is done by local communities it would effectively cover most of the areas visited by local communities.
Cost / Resources:	There may be some costs in adapting the GBRMPA system (such as software upgrades) but the basic system is already in place. There would need to be an intensive communication program in the Torres Strait to get users on-board but this would be a cost effective way for broad surveillance to be undertaken in the Torres Strait.
Timing:	Could be implemented by mid-2015 and would be ongoing.
Data:	The data would come back to GBRMPA under the current system, there would then be a need to get this data to the TSRA (potentially to the LSMU) both as per incident and as summarised data.
Training:	Little to no training required, some potential training on the data side.
Capacity Building:	Little to no capacity building as the system would be run from GBRMPA or the nominated agency.
Management Response:	For each of the types of reporting a management response would need to be formulated, for example for coral bleaching no direct response may be

	required for a particular report, but a direct response may be appropriate for pollution or stranded animals.
Sustainability:	There would need to be continued money allocated to developing the system and to support GBRMPA or whoever maintains it, there would also need to be ongoing promotion of the program in local communities.
Integration with other Programs:	The program would have a direct input into reactive surveys using Manta Tow or RHIS methods and but less so with the other methods.
Issues:	• This program presumes people have mobile phones and internet access, this is true for large areas of the Torres Strait but the system may need to be re-designed to allow for data input after the event. • The program requires constant media promotion to make it successful and a real drive by local people to want to report unusual events in their local communities. • There are potential data privacy issues and some people may not wish to report unusual events because it may indicate where they were at that time, for example this could cause issues where more than one group have access to an area or resource.

Component Two: Monitoring the condition of Home Reefs

Question:	**What is the condition of the reefs around local communities, are there any changes that may be important?**
Rationale:	The intention is to monitor the general health of the reefs around local communities on a regular (twice yearly) basis to give an early warning of changes on these reefs and to identify specific threats such as COTS outbreaks, coral bleaching, coral damage, changes in fish numbers, etc.
Proposed Solution:	The AIMS Manta Tow method provides a rapid and easy method to survey larger areas to identify gross level changes and specific target events such as COTS, coral bleaching, coral disease, etc. The Manta Tow method requires reasonable visibility and so is not applicable in all areas or under all conditions.
Location:	The program would initially focus on reefs around islands where the LSMU Sea Rangers are based and then would expand to areas that were accessible by the Sea Rangers or where the surveys could be combined with existing work such as turtle surveys or other CSIRO/AIMS work. Areas known to be of interest (such as Dungeness Reef) would also be surveyed as resources permit. Note that Manta Tows require reasonable visibility (at least 6 m).
Cost / Resources:	Most of the surveys would be done by the LSMU Sea Rangers and this would be an additional task so the implications of this on the workload need to be investigated. The surveys would require vessels and some snorkelling equipment but it would be at a very modest cost.
Timing:	Surveys would be done in March (post-summer) and November (pre-summer) each year, the first surveys would be done in March 2015.

Data:	The data would come back to AIMS and AIMS would commit to processing this data and making it available via the TS eAtlas as per the current TS data. Simple reports could be provided twice yearly identifying any major changes or events of interest. Note that additional resourcing would need to be provided to AIMS for this work.
Training:	The Manta Tow method requires training to ensure that scoring is consistent across observers. It is recommended that AIMS personnel buddy rangers for one of the sampling campaigns (such as the post-summer surveys) although this type of training would involve additional costs.
Capacity Building:	This would build capacity within the region and allow additional surveys and work to be undertaken with in-region resources.
Management Response:	If the data shows something of interest in an area then follow up Manta Tow surveys could be done both in that area and in surrounding areas to get an understanding of the scale of the issue. This requires some ability to undertake reactive surveys (under the Coral Reef Response Plan) and so some resources need to be reserved for reactive monitoring, where appropriate.
Sustainability:	This program would require ongoing commitment from TSRA via the LSMU and Sea Rangers. Costs for training would need to be covered as would resources to undertake some level of reactive monitoring. Continued access to in-survey vessel is required as is a pool of trained qualified (snorkel and CPR qualifications) personnel.
Integration with other Programs:	This program could form part of a response to events identified under the GBR 'Eye of the Reef' program and Torres Strait Coral Reef Response Plan. The data could identify potential issues that may inform the other monitoring programs.
Issues:	• Any surveys done in local community areas will require permission from the local PBC. • The program requires vessels to be available and for a pool of available trained personnel, there are also potential OH&S issues that need to be addressed.

Component Three: Monitoring Critical Components of TS Reefs

Question:	What is the health and status of the home reef areas?
Rationale:	This component 'drills-down' from the Manta Tow data by conducting Reef Health and Impact Surveys (RHIS) to get estimates of coral cover at fixed sites around the reefs near local communities. In conjunction with this, fish abundance surveys will be done to estimate numbers of the larger locally important fish species. The data will give numerically valid estimates of the major benthic and fish groups and will allow for more subtle changes in reef health to be documented.
Proposed Solution:	The method proposed is the GBRMPA Reef Health and Impact Survey (RHIS) method that can be done on snorkel but using fixed permanently marked sites along with a snorkel based swim-transect fish count method. The solution is partnered with the Manta Tow method with the Manta Tow data providing large-scale synoptic data and the RHIS and fish data providing more detail from the same area. Note that this is only suitable in areas with reasonable visibility.
Location:	These surveys would be done at permanently located sites on the reefs around the local communities and where the Manta Tow surveys have been done. This method can also be used to provide more information from Manta Tow sites where change has been identified and so this can from part of a reactive monitoring strategy with new sites established where disturbance or damage has been found with the Manta Tows.
Cost / Resources:	This method is suitable for snorkel and so can be done with local resources such as the Sea Rangers and would logically be done in conjunction with the Manta Tow method. As such it would require more time from the Sea Rangers but could be accommodated within the existing resources and so would be cost effective.
Timing:	The monitoring would logically be done with the Manta Tow surveys but would only be done annually and the best timing being with the March Manta Tow surveys.
Data:	The data would go to GBRMPA as part of their 'Eye on the Reef' information system, some work may be needed to get reef identifiers for the TS reefs (potentially via the eAtlas). It may be possible that GBRMPA can make a 'dashboard' for the TS data to separate this out from the GBR data.
Training:	There would be a need for initial training (to be negotiated with GBRMPA) and potentially updates to training on a regular basis. Separate training may be required for the fish work. As the surveys are done only annually then some form of update on a yearly basis may be required.
Capacity Building:	This project will develop local capacity in the survey methods as well as consolidate the skills from the Manta Tow component.
Management Response:	It is possible that the component will identify changes that the community will expect a management response to. The initial response should be to undertake more surveys but thought needs to be given to what responses would be appropriate if large scale changes in coral and fish numbers occur

at a series of sites.

In a reverse way this method is useful as a response to changes or issues identified by the Manta Tow or other methods as new sites can be quickly established and surveyed. As a result this method is a key tool in responding to events such as a disturbance on a reef, discovery of COTS outbreaks, coral bleaching and so on. As the method is quick, cost effective and uses local capacity, it is an effective response tool.

Sustainability: Linking this into the Manta Tow method makes this very sustainable as long as local capacity is maintained and training is done on a regular basis.

Integration with other Programs: As this method is about long term change there is little interaction with the other methods although co-locating Manta Tow and Line Transect sites makes sense as the Manta Tow data can give a crude estimate of change that can be confirmed and documented via the line transects.

Issues: The scientific 'rigor' of the RHIS method is weak as it relies heavily on the observer and while there is some replication along a reef it is only good for getting rough estimates of cover and distinguishing gross level changes. The limited size means that you can miss events occurring just outside the sampling area. Combining this with the Manta Tow method increases its usability but training is a key part of implementing the RHIS method.

There is currently no good method for assessing fish numbers on snorkel and so these will need to be developed but getting some measure of the fish is a component missing from the other methods.

Component Four: Monitoring the long-term health of key reefs in the Torres Strait

Question: **What are the long term (decadal) changes in the health of key representative reefs in the Torres Strait and what is causing this change?**

Rationale: The experience from the GBR is that it can take decades to be able to understand longer term trends especially if coral health is impacted by episodic pressures as well as continual pressures. Having a baseline that is updated regularly allows for the documentation of long term changes and potentially the causes (although this requires more frequent surveys).

Once the baselines have been surveyed they provide a permanent record of conditions that can be used in the future and so they form a critical part of understanding change to reefs in the Torres Strait. The intention therefore is that this type of survey be done relatively infrequently but on a well-defined basis allowing for resources to be allocated in advance.

Proposed Solution: Benthic Line Transects, including video or still image recording, undertaken at a number of key locations with an initial wider baseline set of surveys and then regular (every five years) re-surveys of the transects. More frequent surveys can be done in response to results from other components.

Location: The program would initially focus on those reefs that have already been surveyed under the AIMS and CSIRO projects but would review locations to provide a larger baseline to meet future needs such as in areas of anticipated change, stress or impact. Note that Benthic Line Transects can be done in areas of limited visibility (2-3 m) and so it is one method suitable for areas with limited (but some) visibility.

Cost / Resources: As this is specialised work that required SCUBA equipment it would require the involvement of one of the main research agencies such as CSIRO or AIMS, or a suitable consultant. As surveys would be relatively infrequent, it is difficult to build and maintain local capacity for this work and so this is best done by collaborative or other arrangements with the main marine research agencies.

One option is to utilise the current monitoring occurring in the region and to adapt or piggy-back on existing CSIRO surveys. This may require a modification of the CSIRO surveys or additional logistics but may be one way to offset costs and resources.

Depending on the level of collaboration this type of survey would be expensive (especially for vessel time) and so there are significant resource issues around this type of monitoring.

Timing: Surveys can be done any time of the year but require relatively good weather conditions. Surveys would be repeated every five years or so as resources allow, reefs can be selected to align with more frequent manta tow surveys to identify reefs that should be re-surveyed more often. The intention is to re-sample the baseline on a regular basis to update the entire baseline and to do this so that there are enough data points to document decadal level changes.

Data: The data could come back to AIMS and be processed as part of the LTMP project and would therefore have the same outputs as the current data. The final products may also be made available via the TS eAtlas. There would be a need to produce reports after each set of surveys. Again consideration needs to be given as to how this is resourced.

Training: As these surveys would be done relatively infrequently there is little rationale for building local capacity for this work and so it may best be done by external parties that have the resources, including trained personnel, to undertake the work. As a result there would be little in-region training.

Capacity Building: As with the training, it is unlikely that it would be worth building capacity for this type of work in the region so this type of monitoring would not necessarily result in capacity building in the region.

Management Response: This monitoring technique is not designed to look for large changes but more to document longer term trends within episodic events and so there will be no need for reactive responses. What the data will do is provide information for longer term policy level responses and so this monitoring will feed into long term responses around sustainability and ecosystem health.

Sustainability: This program will be difficult to sustain but as a permanent visual record would be taken at each survey, the value of the baseline remains even if follow up surveys are not undertaken. More frequent surveys will allow for factors that cause change to be identified, but even with long periods between surveys the overall level of change can still be found. A good record of current condition will provide a good baseline and benchmark against which change can be measured. This will open opportunities to explore funding for future surveys.

Integration with other Programs: As this method is about long-term change there is little interaction with the other methods although co-locating Manta Tow and Line Transect sites makes sense as the Manta Tow data can give a crude estimate of change that can be confirmed and documented via the line transects.

Issues:

- The ability to utilise existing work in the region, especially the CSIRO monitoring, may reduce costs and increase opportunities.
- This is a potentially expensive program but the implementation of a wider baseline using the NERP data is of importance.
- While it would be good to utilise in-region capacity for this work, in the short-term this is problematic and it is hard to see how local capacity can be developed and maintained based on this work alone (i.e. not as part of another funded project).

Issues:

The design detailed here has a number of issues that need to be worked through before any plan is put forward or implemented. The main one is the lack of a standardised way of measuring the major fish groups/species on snorkel in a way that would be suitable to local Sea Rangers.

Surveying reefs with poor visibility is also an issue and one that CSIRO may have more experience with.

The other main issue is that of data management and the fact that the design relies on a number of agencies each with their own data management systems and expertise. Not only is there is huge reliance on the agency but getting all the data together to get an overall picture of what is happening maybe difficult. The commitment and sustainability of these agencies to the TS data is also unknown and untested.

The major issues identified include:

- Poor to no sampling of fish and turtles/dugongs/etc.;
- Data management – many agencies are involved and there is uncertainty around future commitments;
- Sustainability at all levels from vessels and people to funding to supporting agencies;
- Integration with CSIRO program, uncertain how the current programs can be used to add data to this monitoring;
- Role of Malu Lamar and the relationship between monitoring, response and policy;
- Western reefs/reefs with low undrwater visibility – how to sample these; and
- Reliance on RHIS, which has not been used for long-term studies.

Conclusion

The work completed under the NERP project has created a baseline in understanding and monitoring selected reefs and a unique opportunity to continue this on reefs of the Torres Strait. The combination of in-region capacity, resources and expertise with a deep engagement with the environmental and scientific community creates a point in time where it is possible to implement a program that will help monitor and ultimately protect the reefs of the Torres Strait.

This plan is the start of a longer and broader conversation about how best to monitor and respond to events impacting coals reefs in the region in the context of the of monitoring on the GBR that has document large scale changes and declines on these reefs and in the context of a range of future issues including climate change.

References and Links

1. http://www.marine.csiro.au/marq/edd_search.Browse_Citation?txtSession=7053
2. http://www.nerptropical.edu.au/publication/project-23-technical-report-preliminary-report-surveys-biodiversity-fishes-and-corals
3. http://www.pnas.org/content/109/44/17995.short
4. http://ts.eatlas.org.au/ts
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6. http://www.publish.csiro.au/paper/MF03130.htm
7. http://www.aims.gov.au/docs/research/monitoring/reef/sampling-methods.html
8. http://www.gbrmpa.gov.au/managing-the-reef/how-the-reefs-managed/eye-on-the-reef
9. http://www.gpem.uq.edu.au/oceanography-reports

Appendices

Appendix A. Workshop Goals, Agenda and Participants

Coral Reef Workshop – Thursday the 9th of October, 2014

Location: Australian Institute of Marine Science (Conference Room 2)
Time: 08:30 – 16:30
Chair: Stan Lui

Participants:

- TSRA: Stan Lui, Ron Fujii, Tristan Simpson, Matt Dunn, Frank Loban, Troy Stow, Boggo Gela, Noel Baker and Aaron Bon.
- AIMS: Scott Bainbridge, Hugh Sweatman, Ian Miller, Michelle Jonker, Kate Osborne.
- GBRMPA: Fiona Merida, Roger Beeden.
- CSIRO: Russel Babcock and Darren Dennis.
- JCU/C_2O: Johanna Johnson.
- AFMA: Steve Hall.

Workshop Goals:

- To increase our knowledge and understanding of coral reef monitoring and research outcomes to date within the Torres Strait and the Great Barrier Reef, with emphasis on health trends and threats (updates from AIMS, GBRMPA and CSIRO).
- To discuss and develop the Torres Strait long-term coral monitoring program, including:
    - Short (1-2 years), medium (3-5 years) and long-term (10 year) aims;
    - Review of current capacity of stakeholders (e.g. community, government, research institutes, fisheries) against aims, including skills, training, resources, locations;
    - Discuss monitoring and research method options against aims and capacity;
    - Identify training and skills development requirements against aims and capacity;
    - Discuss stakeholder collaboration strategies to improve networking and data/observation sharing; and
    - Any other suggestions?
- To increase our knowledge and understanding of coral reef/marine preventative and reactive management options in response to potential key issues and threats (e.g. crown of thorns outbreaks, bleaching, disease, oil spill, ocean acidification).
- To identify monitoring and research gaps and priorities and develop strategies to address them.

Agenda:

08:30	Arrive at AIMS, sign in as day visitors
08:50	Welcome to AIMS – Dr David Souter (AIMS Research Manager)
0900	Introductions ***Session 1 – Current and past monitoring of reef resources in Torres Strait*** • Marine resource surveys – CSIRO [~25 min] • Reef monitoring and biodiversity surveys – AIMS [~25 min] • GBR status and threats presentation - If GBRMPA available?
10:00 - 10:15	Morning tea
10:15	***Session 2 – The Torres Strait long-term coral reef monitoring program*** TSRA – Stan Lui to Chair • Introduction • Identifying the goal - Why does the TSRA need coral monitoring? • Identifying issues/threats of concern in the Torres Strait. • Establish short term objectives (1-2 years): – Identify current stakeholder capacity, method options, required capacity, development and training • Establish medium term objectives (3-5 years) – Identify current stakeholder capacity, method options, required capacity, development and training • Establish long-term objectives (10+ years) – Identify current stakeholder capacity, method options, required capacity, development and training.
12:00-12:45	Lunch
12:45	***Session 3 – Management responsibility options for the TSRA and other stakeholders:*** TSRA – Stan Lui to Chair • Torres Strait Coral Reef Response Plan brief – Johanna Johnson [15min] • Using identified issues/threats from previous session discuss and identify passive/active and preventative/reactive management options for the TSRA • Collaboration process – How can the TSRA increase stakeholder networking and data/observation sharing to improve management outcomes? • Community communication and feedback – identify needs and options, including involvement and capacity building. • Other management responsibilities?

14:30 – 14:45	Afternoon tea
14:45	***Continuation of previous discussions – if needed*** ***Session 4 – Future research priorities*** • Identify priority research gaps outside of TSRA resources and capacity to address – what are the bigger questions affecting coral reefs? • Examine other stakeholder capacity to address research gaps, including collaboration options for future projects. • Compile outcomes so that they can be used as justification in the development of future projects.
16:30	Close

Workshop Photo (9 October 2014):