Australian Government

Department of the Environment, Water, Heritage and the Arts

Marine and Tropical Sciences Research Facility (MTSRF) November 2007 Milestone Report

Project 2.5i.2: Early warning and assessment system for thermal stress on the GBR

Project Leader: Professor Ove Hoegh-Guldberg, Centre for Marine Studies, University of Queensland

Summary

A. Refining coral bleaching thresholds.

The aim of this objective is to improve the detection and projection capabilities of bleaching risk in the future. In the MTSRF ARP2 there are five tasks addressing this objective.

These are
(i) the development and testing of ecological/physiological models of the responses of corals to bleaching,
(ii) the use of upwelling as a seasonal predictor of upcoming bleaching events,
(iii) investigating the potential for corals to increase their thermal tolerance through genetic adaptation, (iv) investigating the diversity of naturally occurring zooxanthella types on the GBR, an attribute which is inextricably linked to thermal tolerance and other physiological responses of corals and
(iv) Development of a genetic method to assess bleaching tolerance in corals.

(i) Ecological and physiological modelling (Anthony/Dove).

This task aims to improve our understanding of how different rates of heating in combination with exposure to light and nutrient availability affect the:
(1) bleaching susceptibility of coral to bleaching
(2) carbon acquisition from symbionts
(3) energetics (e.g. lipid formation) and coral vs symbiont growth rates
(4) mortality risk.

The aim will be to produce a range of thermal thresholds for a range of coral species (in particular from the important genus *Acropora*) that are directly linked to down-turns in host and symbiont physiology, but less reliant on simple proxies such as reductions in symbiont densities and dark adapted yields of PSII (Fv/Fm). Our quantitative models will be based on the framework of Dynamic Energy Budget modelling, previously used mainly for unitary organisms. For the purpose of quantifying physiological performance as a function of environmental variation, rate of productivity and associated life functions will be time integrated so as to produce annual energy balance and mortality risk estimates under varying IPCC (2007) scenarios.

(ii) Upwelling as a seasonal forecasting tool of coral bleaching events (Berkelmans).

This task will investigate if there is a link between unusual upwelling activity (normally only seen at the edge of the continental shelf), and coral bleaching events. The 2002 bleaching event was punctuated with large intrusions of cold water (2-4℃) in parts of the central GBR. These intrusions were detectable as far inshore as Magnetic Island (adjacent to the coast near Townsville) and as early as November 2001. If these unusually large upwelling events have a teleconnection to ocean basin-scale oceanographic conditions and resultant weather (as can reasonably be expected), it may be possible to use these upwelling events as a seasonal early warning system for coral bleaching months in advance of a bleaching summer.
The analysis will involve a temporal correlation of bleaching events with in-situ high resolution SST data and a spatial analysis of the extent and influence of intrusions using satellite derived SST and chlorophyll from the MODIS satellite in collaboration with Scarla Weeks (Objective B).

(iii) Genetic adaptation potential of corals (van Oppen/Csaszar)

This task investigates the ability of the coral-algal symbiosis to adapt to warmer sea temperatures in an evolutionary sense. This adaptation will depend on the extent to which there is an underlying genetic component in variation for thermal tolerance. We will therefore estimate heritabilities for a variety of traits related to thermal stress. In the last report, we reported preliminary results from a controlled temperature experiment using *Acropora millepora* from Magnetic Island which harbours predominantly clade D zooxanthellae. These results indicated that there is an underlying heritable component for the efficiency of photosynthesis (Fv/Fm), but only at high temperatures. Since the last report we have been analysing samples from the experiment for different traits, in particular expressed proteins. Considerable time was spent developing the method and assessing protein expression levels as suitable traits. Unfortunately, technical and logistic difficulties preclude the use of expressed proteins as a trait in this study. Work is now underway to use mRNA expression levels as traits instead. This has put the project ~3 months behind schedule. This will mean a delay to the start of the second experiment from January to March 2008 and a delay in the preliminary findings of the second experiment from April to June 2008. The second experiment will involve a C2-dominant population of the same species.

(iv) Diversity of naturally occurring symbiont types (Hoegh-Guldberg/Sampayo)

Reef building corals as well as a number of other invertebrates form an obligate symbiosis with dinoflagellates of the genus *Symbiodinium* (zooxanthellae). This group of symbiotic algae has been shown to be highly diverse and play an important role in determining environmental tolerance ranges of their host.

The original plan for this task was to build an atlas of zooxanthella types based on data from previous collections by a number of different workers on the GBR. It turned out that such an atlas is already under construction at JCU at a global scale. Rather than duplicate existing effort, it is proposed that this task contribute to the limited knowledge we have on the distribution ranges of zooxanthella types on the GBR as previous collections have been mainly restricted to a few locations on the southern GBR (i.e. Heron Island, One Tree Island, Keppels) and mid section of the GBR (Townsville to Mackay area). Substantial variability in symbionts was highlighted by these collections and as such is likely to underestimate the full complexity of host-symbiont associations on the GBR. We have currently identified the far northern section of the GBR as an area of interest and at present collections are being made on sites at and around the Lizard Island area.

The data from these collections will be streamed into the Atlas database to strengthen estimates of the relative sensitivity of regional coral reef communities based on their inherent symbiont populations.

(v) Development of a genetic method to assess bleaching tolerance in corals

Variation in bleaching resistance within and among coral species is due to many factors of both the host and the algal endosymbionts of the genus *Symbiodinium* (zooxanthellae). These include thermal stability of symbiont thylakoid membranes, the ability of the zooxanthellae to dissipate excess light energy, efficiency of repair of zooxanthella photosystem II, anti-oxidant defence mechanisms of the host and symbionts, host tissue thickness, and host pigmentation. Some of these symbiont factors correlate with the identity of the symbiont as assessed by neutral genetic markers (i.e., corals harbouring zooxanthellae of clade D are often more heat tolerant than those associating with clade C). In addition, several of the genes underlying these traits have been characterised. For example, desaturases are relevant to thylakoid membrane stability; heat shock proteins have a function in many cellular stress responses; ubiquitin is involved in the protein degradation process; superoxide dismutases and peroxidases are involved in the anti-oxidant defence mechanism; caspases are involved programmed cell death and the breakdown of the coral-algal symbiosis. Other genes involved in the bleaching response of corals have recently been identified at AIMS and JCU, and set of expressed genes from stressed zooxanthellae has recently been characterised by UQ and JCU.

A key example of the approach we proposed to follow comes from the fish *Fundulus heteroclitus*, where the gene lactate dehydrogenase-B (LDH-B) shows allele frequency differences in populations from distinct thermal environments. This variation has further been shown to result in differences in physiological function and is correlated with differences in survival at high temperatures. Sequence differences in the regulatory regions flanking the protein-coding sequences are now known to result in different levels of lactate dehydrogenase-B expression in the different populations. This work shows that DNA differences can be directly translated into the physiological response of an individual.

The first aim of this project is to develop a genetic technique to assess bleaching tolerance in corals based on sequence analysis of relevant functional genes. Once developed, this technique can be used to assess the vulnerability of corals to climate change and can feed into risk mapping (the GBR Atlas). Genes that will initially be targeted are LDH-B, catalase, and Heat Shock Protein 70.

The second aim is to develop novel molecular markers for the identification of *Symbiodinium*. At present, *Symbiodinium* species and types are mainly identified based on the nuclear DNA ribosomal ITS region. However, due to the nature of this marker (it occurs in hundreds to thousands of copies within each genome, many of which differ slightly in their DNA sequence) and the technical limitations of the electrophoretic methods commonly used to assess variation at ITS regions, much of the true *Symbiodinium* variation may be either confounded or over-estimated when assessed using ITS markers. We therefore propose to develop novel single-copy DNA markers to provide more accurate estimates of *Symbiodinium* diversity.

The two approaches we will initially follow to develop new Symbiodinium ID markers are:

1. We will examine length polymorphisms in the chloroplast 23S ribosomal DNA genes within *Symbiodinium* clade C from the Great Barrier Reef, as this has been shown to be informative for delineation of *Symbiodinium* types in Caribbean clade B. In addition, we will examine the usefulness of single-copy nuclear genes as markers for the identification of *Symbiodinium.*

2. DNA regions flanking microsatellite repeats are known to have high mutation rates. Such flanking regions may therefore provide appropriate variation to serve as single-copy markers to delineate species of *Symbiodinium*. We will assess sequence polymorphisms flanking regions of microsatellite loci developed at AIMS. Sequences of microsatellite loci are available for *Symbiodinium* clade C (C1 and C2) as well as D.

B. Mesoscale oceanographic variability (Weeks, Steinberg, Choukroun)

The primary aim of this objective is to determine the role of mesoscale oceanographic variability in patterns of mass coral bleaching, using satellite and *in situ* data. Patterns of satellite-derived phytoplankton biomass (chlorophyll *a* concentration) are also used to trace the physical dynamics in GBR regional waters.

Acquisition of thermal infrared and ocean colour data from the Moderate Resolution Imaging Spectroradiometer (MODIS) remains ongoing directly from NASA at full 1km resolution, in quasi-realtime. The entire retrospective Terra and Aqua satellite missions (2000-present) have been processed and time series of MODIS 3-day, weekly and monthly sea surface temperature (SST) and chlorophyll *a* concentration have been generated for the GBR and southern GBR regions for analysis.

The relative coral bleaching patterns of the 2001/2 and 2005/6 bleaching events have been determined, and the failure of the NOAA "Hotspots" prediction methodology to predict the 2006 bleaching in the southern GBR explored. We have developed a seasonally adjusted thermal threshold for coral bleaching based on a weekly climatology of sea surface temperatures extending from austral spring to late summer. Our results suggest that the application of thermal-stress algorithms that reflect the long-term mean pattern in seasonal variation allows coral bleaching to be forecast with higher precision (Weeks, Anthony, et al., accepted).

SST and chlorophyll *a* concentration monthly climatologies have been generated from Modis 1km resolution data for 2000-2007 and the SST climatology de-trended against 1985-2001 NOAA AVHRR Pathfinder dataset. To date, monthly anomalies show considerable seasonal and inter-annual variability over the 2000-2007 period, with winter 2007 being coolest, coincident with cold-water bleaching.

A review of relevant physical processes of the GBR with regard to coral bleaching was published in September (Steinberg 2007). The analysis will enable the determination of the relevant oceanographic processes that need to be considered in characterising the thermal environment around coral reefs. Long-term, on-going current meter observations, and an intensive temperature logger array deployed in the Capricorn-Bunker Group during the 2006 bleaching, will be used in the analysis of the cause and distribution of heat stress. These results, together with model calibrations, will feed directly into the related Project 2.5i.1 Regional Climate Scenarios, and assist in the assessment of mesoscale variability from MODIS imagery by Weeks (above).

In situ data from the Heron Island oceanographic array is both providing validation in the analysis of MODIS satellite data, and being used for calibration of a regional hydrodynamic model. AIMS@JCU PhD student, Severine Choukroun, in collaboration with Weeks and Steinberg, is using the UQ MODIS satellite data for validation and interpretation of AIMS in situ data, and to track mesoscale eddies and define their area of generation.

C. Vulnerability of high trophic levels on the GBR (Congdon).

Seabird foraging and reproductive success is explicitly linked to oceanographic variation. The primary aim of this objective is to use state-of-the-art data logging equipment attached to foraging seabirds to investigate the relationship between prey availability/accessibility and specific physiochemical oceanographic parameters.
Preliminary analysis of PTT satellite transmitter data and MODIS satellite data (Congdon & Weeks) confirms the use of 'at-distance' foraging locations by adult shearwaters. Identified locations are up to 1000 km from GBR nesting sites. Analyses of potential within-season SST/ seabird foraging relationships for the black noddy verify that similar relationships exist to those seen previously for shearwaters and sooty terns. This confirms that within-season SST increases cause significant decreases in food availability that impact chick growth and survival across a range of seabirds taxa. A manuscript of this work is in final preparation.
Analyses of potential between-season impacts of large-scale ENSO type phenomenon on reproductive parameters and demography for sooty terns and common noddies in the northern GBR show that breeding participation in both these species is clearly linked to El-Nino precursor intensity, and that this relationship is most likely driven by changes in the depth of the 20m thermocline up to a year in advance of an El-nino event being registered. The reason for this linkage is currently unknown and under further investigation.

For reference: Milestone extracted from Project Schedule

The Description of this Milestone report is:

Project / Task Objectives

(a) Refine threshold values for coral bleaching.

To improve our detection and projection capabilities of bleaching risks in the future, the potential acclimatization and the role of historical adaptation and interactions between key environmental variables new models will be developed. These models will be calibrated using controlled laboratory and raceway experiments in which the responses of a range of coral species to combinations of temperature, light and water quality will be determined. These laboratory experiments will be complimented with detailed analyses of how thermal history, bleaching severity and recovery interact in order to better understand the associated risks of mortality.

This new information will be incorporated in the further development of integrated, multivariate stress algorithms (based on the degree–heating day principle), and risk-based approaches to modeling (e.g. Anthony, Connolly and Hoegh-Guldberg 2006, in press). These thresholds will be incorporated into projection models of how reefs might change as seas warm (Project 2.5i.1: Regional climate scenarios, and Project 2.5i.4: Tools to support resilience-based management in the face of climate change).
How corals are likely to respond to selection for increased thermal tolerance will be investigated by exploring the heritability of key genetic traits within corals and their symbionts. This information will be fed back into this objective to provide more accurate estimates of the trajectory of GBR coral communities under rapid climate change.

(b) To determine the role of mesoscale oceanographic variability in mass coral bleaching patterns.

Specific questions will be addressed in the analysis:

- Does the GBR regional circulation display short-term, seasonal and inter-annual variability, as deduced from Modis satellite data?
- Are the dynamics reflected in remotely-sensed patterns of phytoplankton biomass (chlorophyll *a* concentration)?
- To what extent can physical processes explain spatial thermal stress variability?
- Can hotspots be identified in GBR regional waters from Modis satellite data? Specific events will be examined in detail (e.g. 2002 vs. 2006 coral bleaching periods) to identify the evolution of processes involved.

c) Vulnerability of high trophic levels on the GBR (e.g. sea birds) to climate change.

Seabird foraging and reproductive success is explicitly linked to oceanographic variation. This makes seabirds sensitive indicators of potential climate change impacts at upper trophic levels in the GBR. Project (c) aims to use state-of-the-art data logging equipment attached to foraging seabirds to investigate the relationship between prey availability/accessibility and specific physiochemical oceanographic parameters. This will allow us to better predict how seabirds will respond to projected increases in sea-surface temperature, and so ultimately determine the likely range of oceanographic conditions within which seabird reproduction remains viable.

Specific Objectives

Determine how meso-scale oceanographic variability impacts foraging and reproductive success in wedge-tailed shearwaters. This includes

- Identifying specific foraging locations and/or oceanographic features targeted/used by foraging shearwaters
- establishing the relationship between within-season variation in SST and foraging success/reproductive output.
- establishing the relationship between among-season variation in SST and foraging success/reproductive output

Project Results

1. DESCRIPTION OF THE RESULTS ACHIEVED FOR THIS MILESTONE

(i) Ecological and physiological modelling (Anthony/Dove).

How does the rate of heating affect the physiology of Acropora formosa exposed to sub-saturation light intensities?

This experiment was conducted at Orpheus Island research station with *Acropora formosa* collected from a depth of 5 m held within indoor experimental aquaria illuminated with 100 mmol Quanta m-2s-1. Branches were exposed to a rapid and a slow progressive heating rate and then placed in ambient temperature recovery tanks. Samples for lipid analysis, dinoflagellate densities and pigmentation, and O2 flux data were collected through the course of the experiment. These data are currently being analyzed. The analysis of lipid concentrations however has already revealed significant differences that are attributable to the rate of heating suggesting that thermal history, in addition to light history, can influence the response of reef-building corals to thermal stress and therefore have implications for the modeling of bleaching events. Pnetmax will be standardized to algal densities to determine whether "bleaching" had a positive (potentially driven by higher internal light levels) or negative affect on remnant symbionts. The follow up experiments will be conducted on Heron Island and will include additional measurements such as C14 fixation and incorporation into symbiont and host tissue, and measurements of coral growth rates. These measurements will provide a means for determining whether the allocation of symbiont fixed carbon to host or symbiont is variable under different experimental regimes. Future experiments will then test how these allocations vary for different coral species, and host-symbiont associations.

Energetics approach to estimating coral stress and mortality risk during bleaching events.
This is a modelling paper by Anthony, Hoogenboom and Grottolli - currently being prepared for submission to *Functional Ecology*. The work is a combination of analyses of meta-data on coral energetics and the development of a new energetics model for corals using bleaching severity and time profile as variables. The model integrates the functional relationships between coral bleaching, energy balance, dynamics of energy stores, and associated mortality risk, and uses dynamic energy budget modelling as the theoretical framework. A series of response functions were linked explicitly to relate bleaching to mortality: (1) rates of decline in colony chlorophyll content (bleaching rate), (2) rate of photosynthesis, (3) daily energy deficit, (4) size of energy stores, and (5) coral mortality risk. Model simulations of energy-store dynamics and associated mortality risk for corals (family *Acroporidae*) during bleaching events demonstrated that the timing of the onset of high mortalities is determined by a combination of bleaching rate, event duration and initial energy reserves. Whether a coral dies or recovers from bleaching is critically dependent on whether energy stores are depleted below 5-10% of maximum. These results indicate that energy-costly disturbances occurring prior to bleaching episodes substantially increase the risks of bleaching-induced mortality. The study demonstrates that integrating coral bleaching profiles with physiological energetics provides a strong quantitative framework for identifying scenarios that represent high mortality risk in corals.

(ii) Upwelling as a seasonal forecasting tool of coral bleaching events (Berkelmans).

Summer bleaching events are widely accepted as being due to anomalous sea temperatures (too hot for too long) in combination with high light intensity. Paradoxically, the most severe bleaching event on the GBR in 2002 was accompanied, and even preceded, by large intrusions of cold water onto the continental shelf in the central GBR. Upwelling is a normal phenomenon during the summer months in the central GBR and is due to a rise in the thermocline (normally >100m deep) and a speeding up of the East Australian Current (EAC). Most of the upwelling activity occurs in the central GBR because of a combination of large passages through the outer barrier of reefs and the shape of the continental shelf which forces the EAC to change course from a predominantly southerly direction to a southeast direction. Most upwelling events are only detectable on reefs near the edge of the continental shelf, however in 2002 these cold water intrusions (2-4℃ below ambient) reached as far as Magnetic Island adjacent to the coast and were detected as early as November 2001.
This study hopes to establish if there is a link between unusual upwelling activity and coral bleaching and whether the early detection of upwelling at inshore locations can be used as a seasonal forecasting tool for coral bleaching 2+ months ahead of it actually occurring. The first task is to establish a temporal link between upwelling and bleaching. This requires long-term high temporal resolution temperature data as well as data on the bleaching history of the GBR. A number of in-situ SST data sources have been identified. These include the SeaTemps logger data which cover ~40 sites on the GBR since 1995, the AIMS and GBRMPA weather stations which have been operating at some reefs for up to 20 years, and the AIMS shelf moorings (in collaboration with Craig Steinberg), some of which record temperature in addition to current speed and collectively also span a 20 year period. Historical bleaching records will be obtained from aerial and in-situ surveys, unpublished data held by GBRMPA, ReefBase and the literature. The next task will be to establish the spatial extent and influence of the upwelling. For this I plan to collaborate with Scarla Weeks to investigate whether any of the upwelling detected by in-situ temperature loggers can be seen in either the MODIS SST or chlorophyll data. Scarla has now back-processed the MODIS SST and chlorophyll data (see Objective B) and is in a position to obtain further data (e.g. Pathfinder SST, SeaWifs) from NOAA and NASA though other collaborative links if required.

(iii) Genetic adaptation potential of corals (van Oppen/Csaszar).

The first out of a series of heritability experiments has been completed on a Magnetic Island population of the coral *Acropora millepora* which habours predominantly clade D zooxanthellae. We reported last time that the broad-sense heritability (h^2) was high for both the decrease in maximum capacity of zooxanthella photosystem II (Fv/Fm) under 31 ºC (h^2=0.47), and 32 ºC (h^2=0.5), as well as for the coral growth rates under the same temperatures (h^2=0.62 and 0.55, respectively). In contrast, genetic factors did not contribute that much to the variance observed in both Fv/Fm (h^2=0.24) and growth rates (h^2=0.16) under control conditions (27 ºC). Both traits were always positively correlated, however, only exposure to 32 ºC yielded such results to a moderately large extent (r=0.32).

For this reporting period we were hoping to present the results of additional traits from the first experiment to gain a broader insight into heritability of thermal tolerance. Considerable time was spent investigating the use of differential protein expression by the host coral as heritable traits. This turned out not to be feasible (see below in Problems/Opportunities) and attention has now shifted to investigating host gene expression levels (mRNA) as host traits, which is looking much more feasible. This necessary change of tact has put the project ~3 months behind schedule.

It is anticipated that it the second experiment will commence in March 2008 and that preliminary findings of the second experiment will be available by the end of the reporting year. The second experiment will be on the same species of coral but a population that harbours predominantly clade C2, as opposed to clade D, zooxanthellae.

(iv) Diversity of naturally occurring symbiont types (Hoegh-Guldberg/Sampayo).

The genotype of dinoflagellates (*Symbiodinium*) residing within the tissues of many reef invertebrates appears to be highly diverse and play an important role in determining environmental tolerance ranges of their host. The original proposal was to construct an atlas database of zooxanthella types on the GBR from collections made by a number of researchers. It turned out that this is already underway at a global scale and is being undertaken at JCU. This has called for a change of plan to avoid duplication of research effort (see Activity Changes).

The new proposal is that this task contribute to the limited knowledge we have on the distribution ranges of *Symbiodinium* on the GBR. Previous collections have been mainly restricted to a few locations on the southern GBR (i.e. Heron Island, One Tree Island, Keppels) and mid section of the GBR (Townsville to Mackay area). Substantial variability in symbionts was highlighted by these collections and as such is likely to underestimate the full complexity of host-symbiont associations on the GBR. These collections need to be extended to other sections of the GBR and incorporate inshore as well as outer-reef locations. We have currently identified the far northern section of the GBR as an area of interest and at present collections are being made on sites at and around the Lizard Island area. The sampling design used is targeted to encompass a wide range of species spanning various classes of organisms (Anthozoa, Hydrozoa and Mollusca) that host symbiotic dinoflagellates of the genus *Symbiodinium.* Samples will be taken from as many species as found at each site. Up to 4 individuals will be sampled of each species and at each site this will be done at two depths (deep and shallow). This sampling strategy allows us to: a) obtain diversity estimates on an ecosystem level; b) compare our results to previous work in other locations; c) assess the link between symbiont diversity and environmental parameters in host species with a wide distribution range throughout the GBR. The data from these collections will be streamed into the Atlas database to strengthen estimates of the relative sensitivity of regional coral reef communities based on their inherent symbiont populations.

v) Development of a genetic method to assess bleaching tolerance in corals

The first milestone for this task is due on 10 April 2008, therefore, no information on progress on this task is included in this report.

B. Mesoscale oceanographic variability (Weeks, Steinberg, Choukroun).

Thermal infrared and relevant ocean colour data from the Moderate Resolution Imaging Spectroradiometer (MODIS) have been acquired directly from NASA for the entire Terra and Aqua satellite missions (2000-present) at full 1km resolution. Time series of MODIS 3-day, weekly and monthly sea surface temperature (SST) and chlorophyll *a* have been generated for the GBR and southern GBR regions for analysis. These are being used in a number of inter-project collaborations.

The relative coral bleaching patterns of the 2001/2 and 2005/6 bleaching events have been determined and a seasonally adjusted thermal threshold for coral bleaching developed based on a weekly climatology of sea surface temperatures from austral spring to late summer. This allows bleaching arising due to abrupt warming in early summer to be forecast by using thermal thresholds that appropriately reflect the long-term mean pattern in seasonal variation (Weeks, Anthony, et al., in press).

Monthly climatologies of SST and chlorophyll *a* concentration at 1km resolution have been generated from Modis data for 2000-2007 and compared to the 17 year NOAA AVHRR Pathfinder climatology for 1985-2001, with surprisingly little difference. However, the anomalies generated for the 2000-2007 period show considerable seasonal and inter-annual variability over this more recent period, with winter 2007 being coolest, coincident with cold-water bleaching. Discussion is underway with the AVHRR Pathfinder and MODIS colleagues at Univ of Miami and NASA respectively re (a) release of a 4km AVHRR Pathfinder dataset at 4km resolution for the entire 1985-2006 period, and (b) de-trending the high resolution 1km MODIS dataset againt the longer-term lower resolution Pathfinder dataset.

A review of relevant physical processes of the GBR with regard to coral bleaching was published in September (Steinberg 2007). The analysis will enable the determination of the relevant oceanographic processes that need to be considered in characterising the thermal environment around coral reefs. Long-term, on-going current meter observations, and an intensive temperature logger array deployed in the Capricorn-Bunker Group during the 2006 bleaching, will be used in the analysis of the cause and distribution of heat stress. These results, together with model calibrations, will feed directly into the related Project 2.5i.1 Regional Climate Scenarios, and assist in the assessment of mesoscale variability from MODIS imagery by Weeks (above).

The long-term oceanographic array around Heron Island was serviced and re-deployed on the final voyage of the RV Lady Basten during September 2007. The data is providing the background in situ data to assist in validating and interpreting satellite remote sensing data and calibrating a hydrodynamic model of the region. AIMS@JCU PhD student, Severine Choukroun, is using the UQ MODIS satellite data for validation and interpretation of AIMS in situ data, in collaboration with Weeks and Steinberg.

A review of relevant physical processes of the GBR with regard to coral bleaching was published in September (Steinberg 2007). The analysis will enable the determination of the relevant oceanographic processes that need to be considered in characterising the thermal environment around coral reefs. Long-term, on-going current meter observations, and an intensive temperature logger array deployed in the Capricorn/Bunker Group during the 2006 bleaching, will be used to help analyse the cause and distribution of heat stress. This data is being shared with other MTSRF collaborators and students. These results, together with model calibrations, will feed directly into the related Project 2.5i.1 Regional Climate Scenarios, and assist in the assessment of mesoscale variability from MODIS imagery by Weeks (above).

AIMS@JCU PhD student, Severine Choukroun is analysing the circulation in the Southern Great Barrier Reef, with a paper in preparation (Choukroun, Weeks and Steinberg). The area of interest extends from 22 degrees S to 30 degrees S. The UQ MODIS satellite Sea surface Temperature and chlorophyll concentration data is being used for validation and interpretation of AIMS in situ data. The Okubo-Weiss parameter was also computed from the output of a regional model Bluelink (CSIRO CMAR) to track the eddies in the region or define the area of generation.

ReefTemp (Maynard).

Existing satellite-based systems used to monitor conditions conducive to bleaching are based on low-resolution (50km) SST data. While these systems have served the research and management community well, they have inherent weaknesses that limit their capacity to predict stress on coral reefs at local scales, scales over which bleaching severity is known to vary dramatically.

ReefTemp provides a new operational remote sensing application for the Great Barrier Reef that assesses bleaching risk daily using: high-resolution (2km) SST, regionally validated thermal stress indices, and color-graded legends directly related to past observations of bleaching severity (Maynard et al. submitted). *ReefTemp* can accurately predict bleaching severity at a local scale and therefore help to give focus to the future research and monitoring efforts of managers and researchers.

Ongoing work in this area includes advancing the existing system to include a combined weighted thermal stress index, bleaching risk assessments based on light-temperature interaction, as well as expansion of the program to include the entire Australian EEZ.

Second year milestones for Objective B are on track.

C. Vulnerability of high trophic levels on the GBR (Congdon).

(i) Foraging locations and/or oceanographic features targeted by foraging shearwaters
Preliminary analysis of PTT satellite transmitter data and MODIS satellite data (with S. Weeks) confirms the use of 'at-distance' foraging locations by adult shearwaters. Identified locations are up to 1000 km from GBR nesting sites. To date, two oceanographic regions have been targeted by foraging adults (i) the central Coral Sea seamounts, particularly in the region of Lihou, Marion and Saumarez Reefs and (ii) a large oceanographic gyre off the north coast of NSW.

(ii) Within-season variation in SST and foraging success/reproductive output
Analyses have been completed examining potential within-season SST/seabird foraging relationships for the black noddy. Findings verify that similar relationships exist to those seen previously for shearwaters and sooty terns. This confirms that within-season SST increases cause significant decreases in food availability that impact chick growth and survival across a range of seabirds taxa from different families, including both short and long distance foragers. A manuscript of this work is in final preparation.

(ii) Among-season variation in SST and foraging success/reproductive output
Analyses have been completed examining potential between-season impacts of large-scale ENSO type phenomenon on reproductive parameters and demography for sooty terns and common noddies that breed in the northern GBR. Data for this analysis were obtained by QPWS over a 20-25 year period. Results show that breeding participation in both these species is clearly linked to El-Nino precursor intensity and that this relationship is most likely driven by changes in the depth of the 20m thermocline up to a year in advance of an El-nino event being registered. The reason for this linkage is currently unknown and under further investigation. A manuscript of this work has been reviewed and is now being revised in light of the reviewer's comments for resubmission. A further manuscript comparing the relative impact of these phenomena to impacts attributable to other mortality factors, such as cyclones, is in the final stages of preparation.

Collation of data obtained from SST data loggers.

This task is underway but not complete. (See *Problems and opportunities* below.) Data have been retrieved and verified for all loggers from the first round of deployment. Preliminary analyses are now underway to determine the temporal scale at which the extensive data records for each logger should be sub-sampled effectively.

Relational linking of data on foraging success, provisioning rates, chick developmental rates, and reproductive success to SST data for individual adults

This task is also underway but not complete. A “Microsoft Access” relation database framework has been designed and constructed for the data. Data on nesting success, chick growth and adult foraging parameters are currently being transferred from the existing excel spread sheet formats. Data logger data have not yet been added due to the delays associated with downloading the data loggers as mentioned in *Problems and opportunities* below.

Explanation of Activity changes

Objective A, Task (iv) - Diversity of naturally occurring symbiont types (Hoegh-Guldberg/Sampayo)

It was originally proposed that this Task contribute towards a GBR-wide synthesis of zooxanthella types by assimilating all the published and, where possible, unpublished data from previous studies over the past 10+ years into an atlas database. Through consultation and planning it came to light that such an atlas is already underway at JCU. Rather than duplicate effort, it is proposed that this task extend the knowledge of zooxanthella types by sampling in the far northern GBR (Lizard Island) where little community-wide collection has so far been undertaken. These data will feed directly into the JCU symbiont atlas database.

Problems and opportunities

Objective A, Task (iii) Genetic adaptation potential of corals (van Oppen/Csaszar)

Due to unforeseen technical issues, the initially planned proteome approach for the post-experimental analysis of the coral specimens from the first experiment turned out to be not feasible for the large sample size required for estimating heritabilities. Instead, we are using an assay to investigate the coral population at the transcriptome level using quantitative real-time PCR (qRT-PCR). This will allow for the estimation of heritabilities for gene expression levels in the coral host in response to thermally induced oxidative stress. Due to this change in approach, we expect to have the full results of the gene expression analysis delayed by about three months. Despite these changes, the second heat-stress experiment is expected to start around the initially planned time in March/April 2008. Preliminary results from this experiment are anticipated to be available by the 10 June 2008 reporting deadline.

Objective C, Collation of data obtained from SST data loggers.

This task is underway but could not completed. The process was delayed by the unforseen need to send loggers to the manufacturers in WA for downloading. Preliminary analyses are now underway to determine the temporal scale at which the extensive data records for each logger should be sub-sampled effectively so as to minimise handling and data input times.

This delay has also impacted the task linking data on foraging success, provisioning rates, chick developmental rates, and reproductive success to SST, as mentioned in the section above.

Communications, major activities or events

During milestone reporting period

Book Chapter: Berkelmans R (accepted) Bleaching and mortality thresholds: How much is too much? In: Coral Bleaching: Patterns, Processes, Causes and Consequences (Van Oppen MJH and Lough JM eds). Ecological Studies, Springer.

Book chapter: Congdon B.C**.,** C.A. Erwin, D.R Peck, G.B. Baker, M.C. Double, P. O'Neill (2007) Vulnerability of seabirds on the Great Barrier Reef to climate change In: Johnson J. & Marshall P. (eds) ***Climate change and the Great Barrier Reef.*** Great Barrier Reef Marine Park Authority, Canberra.

Book chapter: Steinberg C (2007). Impacts of climate change on the physical oceanography of the Great Barrier Reef. Chapter 3, Climate Change and the Great Barrier Reef, eds. Johnson JE and Marshall PA. Great Barrier Reef Marine Park Authority & Australian Greenhouse Office

Weeks, S. J., K.. Anthony, A. Bakun, G. C. Feldman, and O. Hoegh-Guldberg, (2007). Seasonal thermal acclimatisation and coral bleaching: Why 2006 predictions failed. Limnology and Oceanography (accepted).

SST Climatology Workshop, 21 August 2007, charied by Scarla Weeks. Minutes are attached as Appendix 1.

Scarla Weeks visited AIMS in August 2007 to meet with Craig Steinberg, Severine Choukroun, Ray Berkelmans and Julian Caley.

Severine Choukroun sepnt visited UQ to work with Scarla Weeks for a week in August 2007 and again in October 2007.

During next milestone reporting period

Craig Steinberg and colleagues at AIMS will participate in a formal discussion group assessing the operational Bluelink product with BoM and CSIRO. This was launched in July 2007 and forecasts, the circulation around Australia a week in advance. See http://www.bom.gov.au/oceanography/forecasts/index.shtml

This will aid and extend the planned regular discussions we are having with Scarla Weeks in order to help explain what and how physical processes are impacting on the GBR from satellite imagery, in situ data and the above operational product.

Invited international workshop presentation:

Congdon B.C. 2007. Assessing the upper trophic level impacts of climate variation in tropical marine ecosystems . In: Seabirds as bio-indicators in the tropical Indian Ocean. *WIOMSA/Ecomar International Workshop*, Victoria, Mahe, Seychelles.

Devney, C., M. Short and B.C. Congdon (2007) Climate change on the Great Barrier Reef: A tern for the worse? Abstracts of ***Australasian Ornithological Conference*** Perth, Australia.

Devney, C., J. Caley and B.C. Congdon (2007) Measuring seabird resilience to climate change on the Great Barrier Reef. Abstracts of ***Australasian Ornithological Conference***, Perth, Australia

A workshop including all participants is tentatively scheduled for February 2007.

Forecast variations to planned milestones

Objective A, Task (iii) Genetic adaptation potential of corals (van Oppen/Csaszar)

- April 10, 2008 Milestone: "Preliminary findings from second heritability experiment with *A. millepora* from Davies Reef. Responsible: van Oppen/ Csaszar [AIMS]" Request that this milestone be slipped to Report 3, due 10 June 2008.
- 10 June, 2008 Milestone: "Findings from the preliminary assessment of the broadsense heritability of thermal tolerance in *Acropora millepora.* Responsible: van Oppen/ Csaszar [AIMS]". Request that this milestone be slipped to the first reporting period in Year 3.