Australian Government

Department of the Environment and Water Resources

Marine and Tropical Sciences Research Facility (MTSRF)
Milestone Report 2, 2006/2007

Program 5i: Climate Change: Great Barrier Reef

Project 2.5i.3: Resilience to climate change

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1. Summary of Milestone Report

The resilience to climate change project is on track, and the targets for all project objectives were met for the 2006/2007 year.

Milestones for the resilience of coral assemblages project area have been delivered with good progress. A publication on the genetic connectivity of coral algal endosymbionts (*Symbiodinium*) on the GBR is approaching completion. Specific primers have been developed for population-level markers targeting additional strains of *Symbiodinium* commonly hosted by corals on the GBR, with marker development and refinement continuing into early 2008. A modelling framework for understanding the potential for corals to evolve greater resistance to bleaching under temperature stress was developed and completed. In June 2007, a workshop will take place on modelling the relationship between thermal anomalies and coral disease and commences activity towards the project objective of identifying links between thermal anomalies and coral disease dynamics.

Milestones for the resilience of reef fish assemblages project area for 2006/2007 have been focussed on reviewing existing literature to produce a preliminary status and trend report on herbivory patterns on the GBR. This report has been completed to schedule and is attached to the milestone report. During 2007/2008, field based activities towards the objectives in this project area will commence. These include surveys of reef fish communities, measures of spatial variation in herbivory, and the susceptibility on inshore macroalgal species to herbivory by mobile herbivores.

2. Summary of Project Objectives

2.1 Resilience of coral assemblages to climate change

(a) Estimate genetic connectivity among GBR populations of coral and their algal endosymbionts to determine their potential for replenishment following disturbances associated with climate change.

Connectivity within and between coral populations is an important component of coral reef resilience. Exchange of larvae creates and maintains high levels of genetic diversity and buffers populations against disturbance. Migrants may carry new alleles that may be integrated into populations through reproduction, creating new gene combinations on which selection can potentially act. The spread of selectively advantageous alleles at DNA loci involved in physiological responses such as bleaching resistance is a potentially important consequence of migration. Furthermore, gene flow increases local effective population sizes, thereby enhancing the ability of populations to resist rapid random changes in allele frequencies from one generation to the next through drift. Larval-exporting or source reefs with diverse populations of healthy adult corals are essential to maintain the genetic diversity and resilience of larval-importing or sink reefs. Therefore, an

assessment of larval transport in and out of reefs, i.e. the extent to which reefs are self-seeding or accumulate recruits from surrounding areas, as well as the direction of larval dispersal will improve our ability to forecast how reef corals are likely to respond to environmental change. Successful migrants leave a genetic signature of their movements and allow inference of connectivity using population genetic methods. We will estimate genetic connectivity among GBR populations of coral and their algal endosymbionts using analysis of DNA microsatellite loci, and link this information to hydrodynamic models to provide improved estimates of reef connectivity.

(b) Identify mechanisms of adaptation available to local coral populations to understand their potential for adaptation to climate change.

Observed differences in bleaching sensitivity between geographically distinct, conspecific coral populations may be caused by differential expression of genes involved in the bleaching response (as a consequence of either local adaptation or acclimatisation), and/or by the presence of distinct alleles at these loci (due to selection and local adaptation). We will identify fast diverging genes (that are therefore likely to be under selection) in a GBR coral species that is known to show a latitudinal gradient in thermal tolerance using DNA microarray technologies. Common garden experiments and microarray/quantitative real time PCR analyses will subsequently be used to examine whether or not genetically determined (i.e. a consequence of selection and hence reflecting adaptation) differences in gene expression levels exist between these latitudinal populations.

DNA sequence analysis of a subset of the genes identified as fast evolving will reveal whether selection on the DNA sequences themselves has occurred in these populations. Theoretical models of the potential for corals to evolve greater bleaching resistance in response to climate change will be developed as part of this objective. Results from the empirical studies described above will be used to parameterise these models and model outputs will be used in turn to guide the design of further experiments.

(c) Identify links between thermal anomalies and coral disease dynamics to predict the response of coral assemblages to ocean warming associated with climate change.

Increases in the severity and frequency of wildlife disease epidemics over the past three decades are thought to be linked, in part, to increasing thermal stress associated with climate change. Understanding the implications of increasing ocean temperatures for the spread of coral pathogens and for disease resistance of corals will significantly enhance current understanding of the resilience of GBR coral assemblages in relation to climate change. We will determine the linkages between seasonal thermal anomalies and the prevalence of coral disease. A modelling approach will be used to evaluate metrics of thermal anomalies based on NOAA satellite data that best explain spatial and temporal patterns in the prevalence of coral disease on the GBR. The relationship between peaks in disease prevalence and thermal anomalies will be analysed to determine thermal thresholds associated with outbreaks of coral disease. We will also identify interactions between bleaching and disease. We aim to produce algorithms to (a) relate temperature to past disease outbreaks, and (b) develop a product that provides predictive outlooks for outbreaks of key coral diseases, similar to the NOAA hotspot algorithm that predicts bleaching events.

2.2 Resilience of reef fish assemblages to climate change

(d) Quantify current levels of herbivory by reef fishes on the GBR and evaluate the extent to which reefs across the GBR shelf are vulnerable to ecosystem phase-shifts and domination by macroalgae as a result of climate change.

Herbivory has long been considered as one of the primary determinants of coral reef community benthic structure. It was not until recently however, that research efforts began to focus on understanding the role of herbivory in maintaining ecosystem function, and thus quantify the importance of herbivores on coral reefs. The primary goal for this objective in 2007 is to prepare a status and trend report on herbivory by reef fishes on the GBR and to evaluate the extent to which reefs across the GBR shelf are vulnerable to ecosystem phase-shifts and domination by macroalgae as a result of climate change. This review address issues such as global and local trends in reef herbivory studies, the number of publications based on herbivory, the nature of herbivory on the GBR, and the scale and distribution of such studies. These data will be reviewed in order to produce a status and trend report on herbivory patterns.

(e) Identify critical thresholds in macro-algal phase shifts and evaluate alternate management strategies in order to limit the impacts of climate change on the ability of fish assemblages to prevent ecosystem phase-shifts on coral reefs.

Climate change will influence the community structure of reef fish assemblages, however, it is unknown if these changes will affect ecosystem processes, and subsequently lead to a phase shift from coral to algal dominated reefs. Here, we will utilise and build on existing databases of the distribution and abundance of herbivorous fishes across the GBR to quantify current rates of herbivory. These data will be combined with direct experimental analyses of fish-algal interactions that will enable us to estimate the current capacity of GBR reef fish populations to maintain low macroalgal cover on mid and outer reefs. The second part of this objective will use a modelling approach to permit direct estimation of critical thresholds in the coral – macroalgal phase shift and to evaluate alternative management strategies to respond to changes in macro-algal distributions. We will combine the results from part one with existing algal distribution data and algal growth trajectories to model fish-algal interactions and outcomes under a range of climate change scenarios. Furthermore, it will provide us with an indication of the relative resilience of different components of the GBR ecosystem. In particular, it will indicate to what extent the current stands of macroalgae on inshore reefs reflect a state of heightened vulnerability to climate change.

(f) Evaluate the long term recovery and resilience of reef fish communities to climate change induced habitat degradation.

The most immediate and substantial effects of climate change on coral reefs are severe episodes of climate-induced coral bleaching, which cause widespread mortality of reef corals. Extensive mortality of reef corals results in the loss of essential habitat for coral reef fishes, leading to reduced abundance and localised extinction of coral reef fishes. While many studies have documented sudden declines in the abundance of fishes immediately following extensive coral depletion, the degree to which fish communities are resilient and may eventually recover is currently unknown.

We will conduct a detailed analysis of the recovery and resilience of fish assemblages at Trunk Reef, central GBR, which were severely impacted by climate induced coral bleaching in 2001-02. Recovery of reef fish assemblages is likely to be contingent upon increases in coral cover and a return to pre-disturbance structure of benthic communities. Changes in the structure and dynamics of fish communities will be monitored annually and directly compared to temporal changes in the physical and biological structure of benthic habitats.

3. Project Results

Summary of progress on activities conducted against project objectives, listed below.

Objective	Targeted Activity	Completion Date
(a)	Report of the genetic connectivity among *Symbiodinium* populations hosted by the soft coral, *Sinularia flexibilis*, on the GBR. Analyses of genetic diversity of Symbiodinium in this species before and after mass bleaching events. [AIMS/JCU]	June 2007
(a)	Development of microsatellite markers for study of genetic connectivity among populations for a range of *Symbiodinium* strains hosted by hard corals. [JCU]	Mar 2008
(b)	Report of theoretical models of the potential for corals in the GBR to evolve greater bleaching resistance in response to climate change. [AIMS]	June 2007
(b)	Collection of colonies from different thermal environments to establish baseline expression levels of genes involved in bleaching response. [JCU]	June 2007
(c)	No funding/activity in Year 1	2008-2009
(d), (e)	Preliminary status and trend report of herbivory patterns by fishes on the GBR, relationship to reef closures, ecosystem health and climate change on reefs on the GBR. [JCU]	May 2007
(f)	No funding/activity in Year 1	2008-2010

- **Report of genetic connectivity among *Symbiodinium* populations hosted by the soft coral, *Sinularia flexibilis*, on the GBR. Analyses of genetic diversity of *Symbiodinium* in this species before and after mass bleaching events.**

  Additional data were obtained to build on the findings of a JCU honours project which examined spatial and temporal patterns of genetic diversity and differentiation among *Symbiodinium* (zooxanthella) populations hosted by the soft coral, *Sinularia flexibilis*.

  This project was completed in June 2006 by E. Howells and funded by the ARC CoE, AIMS and AIMS@JCU, and MTSRF funding has subsequently been allocated to incorporate additional molecular data (i.e. genetic variation at new microsatellite loci) into this research project, with the aim of increasing robustness in the initial patterns observed. *Symbiodinium* spatial and temporal sample sets (approximately 1,000 coral samples containing a specific clade C strain of *Symbiodinium)* were genotyped with two newly available microsatellite loci (developed at AIMS). Microsatellite allelic fingerprints were scored and combined with the initial data set generated during the honours project. The updated data set was re-analysed using a range of traditional statistical methods and a Bayesian model of population structure. Preparation of the updated results in a manuscript for publication is currently being finalised, with an anticipated date of submission in August 2007. This project is mostly on track, with the spatial connectivity component approaching completion. *Symbiodinium* population samples taken before and after bleaching events have been genotyped at AIMS with the new microsatellite markers, but the data analysis of temporal trends has not yet been completed.

- **Development of microsatellite markers for study of genetic connectivity among populations for a range of Symbiodinium strains hosted by hard corals.**

  Enriched microsatellite libraries for three *Symbiodinium* strains (C1, C2 and D) commonly hosted by hard corals on the GBR have been sent to the Australian Genome Research Facility (AGRF) for cloning and sequencing. 192 sequences from *Symbiodinium* strain D have been received from AGRF so far and approximately 20 clones contained suitable microsatellites.

Specific primers have been designed for these microsatellites. A further 192 sequences for Clade D *Symbiodinium* and 384 sequences each for Clade C1 and C2 *Symbiodinium* are expected shortly. Based on our success rate in the first batch of sequences, this effort will allow us to design approx 40 primers per *Symbiodinium* strain. This will provide the tools to study genetic connectivity among *Symbiodinium* strains and populations on the GBR. This project is on track.

- **Report of theoretical models of the potential for corals in the GBR to evolve greater bleaching resistance in response to climate change.**

  We have completed the development of a modeling framework for understanding the potential for corals to evolve greater resistance to bleaching under temperature stress. While temperature is the stressor modelled, this modeling framework should be applicable to the evolution of resistance to other stresses and other mutualistic symbioses. The model is structured in two parts: one captures the ecological dynamics of bleaching and the other the evolutionary dynamics in terms of population genetics. On the ecological side, rates of association and dissociation of corals and zooxanthallae are modelled. On the evolutionary side, two di-allellic loci, one in the coral and one in the zooxanthallae, are modelled. One allele at each locus confers bleaching resistance while its alternate allele does not. The frequency of these alleles are then tracked to see under what conditions the temperature resistant allele might become dominant in the coral and/or zooxanthallae populations. Because the evolution of bleaching resistance involves the evolutionary dynamics of two interacting genomes as part of the coral symbioses, establishing this framework required the development of two new concepts of how selection may operate. These concepts are interspecific linkage disequilibrium and interspecific epistatic gene interactions which account for the relationship between genes in separate genomes.

- **Collection of colonies from different thermal environments to establish baseline expression levels of genes involved in bleaching response.**

  Coral colonies from populations in different thermal environments have been identified and tagged. Samples have been collected from these colonies on two occasions to date and have been stored appropriately to allow analysis of baseline gene expression patterns. This project is on track.

- **Preliminary status and trend report of herbivory patterns by fishes on the GBR, relationship to reef closures, ecosystem health and climate change on reefs on the GBR.**

  This project was completed to schedule.
  See attached preliminary status and trend report:

  Cvitanovic C, Fox RJ, Bellwood DR (2007)
  Herbivory by fishes on the Great Barrier Reef: a review of knowledge and understanding

4. Summary of Communication Activities

- **Bette Willis and Line Bay @ JCU 23/3/07, 30/4/07, 02/05/07**
  During these meetings the progress on the Symbiodinium microsatellite libraries were discussed in addition to the sampling design for objective a and b to be reported on Dec 2007

- **Madeleine van Oppen and Line Bay @ AIMS 21/3/07, 01/05/07**
  During these meetings the progress on the Symbiodinium microsatellite libraries were discussed in addition to the sampling design for objective a and b to be reported on Dec 2007

- **Bette Willis, Madeleine van Oppen, Line Bay and Allison Paley @ JCU**
  During this meeting the potential to examine genetic connectivity of Symbiodinium hosted by *Acropora millepora* in the Palm group was discussed.

- **Troy Day, Laura Nagel, Bette Willis, Madeleine van Oppen, Julian Caley and Line Bay @ JCU 04/05/07**
  Troy Day presented a seminar on the modeling results from objective b so far. This was followed by a general discussion about the biological properties of the coral-Symbiodinium symbiosis and their implications on the modeling results.

- **Madeleine van Oppen, David Miller and Line Bay @ JCU 26/02/07**
  During this meeting the design of a microarray experiment to test the relative roles of acclimation and adaptation on differential gene expression of corals was discussed.

5. Contribution of AIMS Activities to Completion Plan for Out Years Activities, and Completion Plan for Remaining Activities in Out Years

Objective	Targeted Activity	Completion Date
(a)	Assessment of small scale population structure and genetic connectivity among populations in the *Acropora aspera* group	June 2008
(b)	Assessment of expression levels of genes involved in the bleaching response in coral populations from different thermal environments	June 2009
(b)	Understanding of the role of selection on expression levels of genes involved in the bleaching response	June 2010
(c)	No activity Year 1	
(c)	Complete surveys of coral disease prevalence at key sites missing from JCU / AIMS LTMP coral disease surveys.	Mar 2008
(c)	Analyse patterns in coral disease prevalence on the GBR in relation to seawater temperature patterns.	June 2008
(c)	Develop a model to predict the likelihood of coral disease outbreaks in response to ocean warming.	Dec 2008
(c)	Present report on the vulnerability of GBR corals to disease in relation to ocean warming.	June 2009
(d), (e)	Collate available data on herbivory patterns on GBR	Dec 2006
(d), (e)	Develop a protocol for quantifying the capacity of inshore reef fish communities to respond to local macroalgal growth; directly identifying the critical functional groups responsible for macroalgal browsing.	Dec 2007
(d), (e)	Complete experimental evaluation of relative susceptibility of dominant inshore macroalgal species to browsing by mobile reef herbivores.	June 2008
(d), (e)	Evaluate Island-scale variation in herbivory on macroalgae using a hierarchical design to explore site and local variation in browsing rates.	June 2008
(d), (e)	Report on Island-scale variation in herbivory and estimated capacity of inshore reefs to respond to increased increased macroalgae.	June 2008
(d), (e)	Complete regional scale evaluation of inshore reef susceptibility to coral-algal phase-shifts and ecosystem collapse. Initiate compilation of herbivore abundance data and preliminary evaluation of ecosystem thresholds.	June 2009
(d), (e)	Complete field and experimental evaluation of algal ecosystem thresholds, modeling of coral algal phase shifts under different climate change scenarios.	June 2010
(d), (e)	Present report on vulnerability of GBR to climate change induced shifts in macroalgae distribution and abundance in relation to fish herbivory and present options for alternate management options.	Dec 2010
(f)	No activity Year 1	
(f)	2007-08 surveys of fish assemblages on Trunk Reef. Report on trajectories for coral cover and fish populations 5-yr post-disturbance.	Mar 2008
(f)	Publish scientific paper based on 2002-2008 results.	Dec 2008
(f)	2008 surveys of fish assemblages on Trunk Reef. Compare fish and coral communities at Trunk Reef to pre-disturbance structure, as well as against other reefs with contrasting disturbance histories	June 2009

Objective	Targeted Activity	Completion Date
(f)	2009 surveys of fish assemblages on Trunk Reef Establish key factors and limitations to recovery in highly disturbed fish communities. Briefing to end-users GBRMPA, DEH, DPI&F.	Dec 2009
all	Final end-user briefings, seminars or workshops to communicate results and contribute to management strategies. Publish and disseminate peer-reviewed scientific publications	June 2010

6. Summary of Annual Project Achievements for 2006/2006

6.1 Resilience of coral assemblages to climate change

The MTSRF proposal for objective (a) in 2006/2007 was to complete an assessment of the genetic connectivity of *Symbiodinium* populations hosted by a soft coral on the Great Barrier Reef (GBR) and develop microsatellite markers for additional strains of *Symbiodinium* which are commonly hosted by hard corals in this region. This commenced with a preliminary assessment of the results of an honours project on genetic diversity and differentiation of 12 reef populations of *Symbiodinium* hosted by the soft coral, *Sinularia flexibilis*, spanning 1,300 km of the GBR during 2006. Additional molecular genotyping, subsequent data analysis and write-up during early 2007 led to the achievement of a manuscript of publishable quality, to be submitted in August. This publication was the first investigation of the genetic diversity and connectivity of *Symbiodinium* populations in the GBR region, and contributes to a very limited body of knowledge on the natural population ecology of coral endosymbionts. The major findings were that while high levels of genetic diversity exist within *Symbiodinium* reef populations, barriers to gene flow prevent this diversity form being uniformly distributed across the GBR, and over time significant genetic differences have accumulated among all 12 surveyed populations. Population structure was consistent with restricted hydrodynamic transport via the broad-scale patterns of water circulation within the GBR lagoon. It is proposed that restrictions to dispersal in this particular clade C strain of *Symbiodinium* arise from a short duration in the water column due to either, or a combination of, a benthic free-living existence in the sediments, negative buoyancy (non-motile phase) and limited migrations into the water column (flagellated phase), or poor survival outside of a nutrient-rich host environment. In the face of global warming, barriers to gene flow among the investigated populations of *Symbiodinium* indicate that this zooxanthella strain is particularly susceptible to losses of genetic diversity (potentially experienced during coral bleaching) as there is little opportunity for any losses of genetic diversity within populations to be mediated by migration. To develop a wider understanding of the importance of different factors that drive patterns of *Symbiodinium* population connectivity and resilience for different host-zooxanthella combinations, it is necessary to develop population-level molecular markers that target the *Symbiodinium* strains commonly hosted by a range of corals on the GBR. For 3 of the most common strains of *Symbiodinium* (C1, C2, D) hosted by hard corals on the GBR, microsatellite libraries were developed during 2006/2007 and a number of specific primers were developed. During the next year, additional specific primers will be developed (approximately 40 primers per strain) and subsequently tested for their applicability in detecting genetic variation. In combination with markers targeting host DNA, this will enable connectivity and resilience to be examined in various host-zooxanthella partnerships that differ in aspects of both host and symbiont ecology, and the susceptibility of the partnership to disturbance (e.g. coral bleaching).

For objective (b), a modeling framework for understanding the potential for corals to evolve greater resistance to bleaching under temperature stress is now complete, and population sampling of corals for experiments measuring gene expression levels in coral-*Symbiodinium* partnerships originating from different thermal environments has commenced. Initial tagging and collecting of coral colonies from different thermal environments commenced in 2007 for analysis of baseline gene expression patterns in 2007/2008.

While there was no funding or research activity for objective (c) in the 2006/2007 year, this project will be kick-started with a workshop on modelling the relationship between thermal anomalies and coral disease at Cornell University (Ithaca, NY) on June 3-5, 2007. Workshop participants will include modellers (P. Mumby, U Exeter; J. Bruno, U N. Carolina), NOAA researchers (M. Eakin, S. Heron), and coral disease experts (B. Willis and C. Page, JCU; D. Harvell, Cornell U). The workshop will focus on modelling disease outbreaks following the 2005 bleaching event in the Caribbean. In year 2, we will develop the model to explore the relationship between disease and temperature on the GBR.

6.2 Resilience of reef fish assemblages to climate change

For objectives (d) and (e) the main focus this year has been to thoroughly review the available literature so that we may more effectively quantify current levels of herbivory by reef fishes on the GBR. The results identified significant knowledge gaps, particularly in identifying herbivores, obtaining robust quantification of abundances and, primarily, in quantifying variation in the nature and intensity of herbivory across the reef. Herbivory on macroalgae was particularly poorly understood in terms of the taxa responsible for algal removal. One of the key objectives is to evaluate the extent to which reefs across the GBR shelf are vulnerable to ecosystem phase-shifts and domination by macroalgae as a result of climate change. It was clear from the existing literature that our knowledge base was extremely limited in terms of both the spatial scale of studies and taxonomic resolution. Although research on herbivory on the GBR quantitatively lags behind that of other countries, probably reflecting the relatively intact nature of the GBR compared to collapses elsewhere, recent findings have emphasised the potential for reef resilience. In addition to a comprehensive literature search and a through evaluation of the available evidence, work in the current year included preparation for an intensive field season in the 2007/2008 year.