Australian Government
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Marine and Tropical Sciences Research Facility Milestone Report, March 2009

Program 7: Halting and Reversing the Decline of Water Quality

Project 3.7.1: Marine and estuarine indicators and thresholds of concern

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Summary

All milestones are on track.

Biofilms: Experiments exposing foraminifera in aquaria to different water quality conditions are ongoing. We have also tested if organic carbon and nitrogen content of foraminifera reflects local water quality conditions. This has been achieved in three field exposure experiments, and data are currently being analysed. Work on bacteria as indicators for water quality is ongoing with repeated sampling of sediments and biofilms in the field now under way. Two field trips to the Whitsundays were conducted, for deployment and retrieval of potential indicator species along water quality gradients.

Corals: Four manuscripts on coral indicators and ecosystem resilience at changing water quality have been completed. All field work and much of the laboratory work to test the validity of the Whitsundays indicators in three other regions (Fitzroy, Burdekin and Wet Tropics) has been completed, and results are presently being written up.

Seagrass: Preliminary analysis of data collected in Task 1.1.3 and the intertidal seagrass component of Reef Rescue MMP are completed, suggesting that epiphyte cover and epiphyte biomass data are poorly related. This appears to be primarily a consequence of the difficulty quantitatively sampling epiphyte biomass. Analysis and interpretation of mapping and monitoring data from Cooktown to Hervey Bay is continuing, with a focus on identifying physiological and morphological measures and indicators of meadow resilience in response to changing water quality. Preliminary interpretation was presented in Issue 35 of Seagrass-Watch News (www.seagrasswatch.org).

Estuaries: Work to develop tools for evaluation of estuarine ecosystem condition is progressing well, except for interruptions of field work due to floods. Data up to September 2008 already analysed. They show that fish fauna is very site specific, and strongly varies between seasons. They also show that estuary specific faunal patterns and seasonal changes are very robust, with consistent seasonal change across sites and the maintenance of site specific faunal patterns, despite samples analysed so far coming from the high recruitment season and despite extreme seasonal flooding with the potential to flush fish from the small estuaries sampled. Consequently, it should be possible to define optimal times to conduct studies to assess estuary condition. This surprising consistency also

indicates that there is great potential in developing the use of process-specific variables as measures of estuary condition.

Project Outputs / Milestones

Objective	Targeted Activity	Due Date
(a)	Field testing and analysis of marine biofilms (bacteria, diatoms, foraminifera) for their suitability to indicate changes in water quality. [AIMS]	June 2009
(b)	Field testing and analysis of coral reef organisms and physiological change tested for their suitability to indicate changes in water quality and ecosystem condition. [AIMS]	June 2009
(c)	Contribution to research on seagrass communities and their responses to changing environmental conditions along the Queensland coast. [QDPI&F]	June 2009
(d)	Conduct research towards identifying potentially useful ecological indicators of the condition of North Queensland's estuaries. [JCU, GU]	June 2009

Project Results

Description of the results achieved for this milestone

a. Field testing and analysis of marine biofilms (bacteria, diatoms, foraminifera) for their suitability to indicate changes in water quality. [AIMS]

On track: A variety of experiments exposing foraminifera to different nutrient concentrations in aquaria is still ongoing, some of these testing interactive effects of light/temperature and nutrients. One Honours student (C. Altenrath) has submitted her thesis investigating the effects of nutrient addition and increased temperatures on two foraminiferan species. The two species tested showed stronger effects of temperature, with increasing growth rates at enhanced temperature. Studies on other species have also indicated distinct reductions in growth rates due to Nitrate or Phosphate additions. In total four large-scale transplant experiments have now been completed, each involving two field trips to the Whitsunday for deployment and retrieval. Data are still being analysed but indicated that the species transplanted grow distinctly better in areas further from the mainland less impacted by runoff. We have now also developed methods to measure organic carbon and nitrogen in individual foraminifera of three species and will test if C/N ratios in foraminifera can be used as indicators for nutrient status of reefs or health indicator for foraminifera. Integration of foraminifera samples into the Reef Water Quality Plan monitoring is now well established, with three sets of sediment samples for foraminifera analysis received to date. A manuscript discussing relationships between water quality, coral- and foraminiferan communities on the Reef Plan reefs is about to be submitted. The effect of herbicides (diuron) has now been tested on fourteen foraminiferan species (PhD thesis, J. v. Dam) and effective concentrations have been calculated. Initial tests have also been conducted with three herbicides and crustosa coralline algae. Experiments on the interactive effects of herbicides and temperature increase (global change) are in preparation. Work on bacteria as indicators for water quality is also on track. Sediment samples and biofilms (on slides exposed for four to five

weeks) have now been repeatedly sampled along the Whitsunday water quality gradient and sampling stations at Magnetic Island established to investigate short term temporal variations. Development of a fast fingerprinting technique to describe bacterial diversity on biofilm and sediment communities is in progress.

b. Field testing and analysis of coral reef organisms and physiological change tested for their suitability to indicate changes in water quality and ecosystem condition. [AIMS]

(1) A review of a recommendation of eleven indicators for inclusion in monitoring programs has been submitted as a manuscript:

Cooper TF, Gilmour JP and Fabricius KE (in review) Coral-based bioindicators of changes in water quality on coastal coral reefs: A review and recommendations for monitoring programs. *Coral Reefs.*

This paper reviews the suitability of a range of bioindicators for use in monitoring programmes linking changes in water quality to changes in the condition of coral reef ecosystems. From the literature, 21 candidate bioindicators were identified whose responses to changes in water quality varied spatially and temporally; responses ranged from rapid (hours) changes within individual corals to long-term (years) changes in community composition. From this list, the most suitable bioindicators were identified by determining whether responses were, i) specific, ii) monotonic, iii) variable, iv) practical, and v) ecologically relevant to management goals. For long-term monitoring programmes that aim to quantify the effects of chronic changes in water quality, eleven bioindicators were selected: symbiont photophysiology, colony brightness, tissue thickness and surface rugosity of massive corals, skeletal chemistry, abundance of macro-bioeroders, micro- and meiobenthic organisms such as foraminifera, coral recruitment, macroalgal cover, taxonomic richness of corals and the maximal depth of coral reef development. For short-term monitoring programmes or environmental impact assessments that aim to quantify the effects of acute changes in water quality, a subset of seven of these bioindicators, plus partial mortality, were selected. The choice of a subset of these bioindicators will depend on the specific objectives and the timeframe available for each monitoring programme. An assessment framework is presented to assist in the selection of bioindicators to quantify the effects of changing water quality on coral reef ecosystems.

(2) Completed: Fabricius KE (in review) Factors determining the resilience of coral reefs to eutrophication: a review and conceptual model. Book Chapter In: Z Dubinski (ed): Corals and Coral Reefs. Springer.

This book chapter reviews the main impacts of eutrophication on the ecology of coral reefs, and the properties of reefs that determine their exposure, resistance and resilience to it. It shows that eutrophication affects coral reefs by way of nutrient enrichment, light loss from turbidity, and the smothering and alteration of surface properties from sedimentation. These changes lead to changes in trophic structures, reduced coral recruitment and diversity, the replacement of corals by macroalgae, and more frequent outbreaks of coral-eating crown-of-thorns starfish. The reefs and areas most susceptible to degradation from pollution are deeper reef slopes, reefs located in poorly flushed locations and surrounded by a shallow sea floor, frequently disturbed reefs, and reefs with low abundances of herbivorous fishes. The chapter concludes with a conceptual model of the main links between water quality and the condition of inshore coral reefs.

(3) Completed our manuscript on our (previously reported) study on the strong interactive effects of nutrients and sediments on coral fertilisation rates:

Humphrey, C, Weber M, Lott C, Cooper T and Fabricius KE (2008) Effects of different types of sediment, dissolved inorganic nutrients and salinity on fertilisation and embryo development in the coral *Acropora millepora*. Coral Reefs 27: 837-850.

(4) Completed manuscript on the scientific basis for the GBR Water Quality Guidelines:

De'ath G, Fabricius KE (in review) Water quality as regional driver of coral biodiversity and macroalgal cover on the Great Barrier Reef. *Ecological Applications.*

This study models the relationships between large-scale data on water quality and measures of reef status along the whole of the Great Barrier Reef (GBR: 12° to 24°S). Large-scale data on water clarity and chlorophyll showed strong regional differences in GBR water quality, with water clarity increasing > three-fold from inshore to offshore waters, and chlorophyll increasing ~two-fold from inshore to offshore and ~two-fold from south to north. Four biotic groups comprising macroalgal cover and the taxonomic richness of hard corals, phototrophic and heterotrophic octocorals were predicted from water quality and spatial location. Richness of hard corals and phototrophic octocorals declined with increasing turbidity and chlorophyll, whereas macroalgae and the richness of heterotrophic octocorals increased. Macroalgal cover experienced the largest water quality effects, increasing five-fold with decreasing water clarity and 1.4 fold with increasing chlorophyll. For each of the four biota ~45% of its variation was predictable, with water quality effects accounting for 18-46% of that variation. Effects were consistent with the trophic requirements of the biota, thereby suggesting control by energy supply limitation. Throughout the GBR, mean annual values of >10 m Secchi disk depth (a measure of water clarity) and <0.45 g L-1 chlorophyll were associated with low macroalgal cover and high coral richness. Our models suggest these values as useful water quality guidelines. Of the 2,833 gazetted reefs in the GBR, 22.8% exceeded these guideline values. The models also show that compliance with the guidelines, e.g. by minimizing agricultural runoff, would likely reduce macroalgal cover by 39% and increase hard coral and octocoral richness by 16% and 33%, respectively, on the reefs where guidelines are presently exceeded.

(5) The 26 days of field work to collect coral indicator samples from twelve reefs along water quality gradients each within four of the Reef Plan monitoring regions are completed. The trip was conducted as a collaboration with the Reef Plan Monitoring Team (water quality and inshore monitoring teams), and JCU student Helene LeGrand. Physiological and community indicators were sampled at two depths at each reef. The field indicator data included coral pigmentation, macro-bioeroder densities, surface complexity, partial mortality, and coral and octocoral juvenile densities and species richness. Laboratory samples for skeletal density, protein and pigmentation are completed, and data processing and RNA/DNA ratios will be conducted in the coming weeks.

(6) Most internal macrobioeroders (sponges, bivalves, polychaetes, sipunculans and barnacles) are filter feeders, and a number of previous studies have investigated whether their densities change with eutrophication. We have completed a review of the existing literature on macrobioerosion. This review suggests that the number of studies on the use of bioeroders density to indicate changes in water quality have resulted in contradictory conclusions. The majority of studies find an increase in total bioeroders densities with increasing nutrient levels. Especially bivalves and sponges tend to have

higher densities in nutrient-enriched than in oligotrophic waters, whereas polychaetes and sipunculans often do not vary in density but in their community composition. In order to test if the density of internal macrobioeroders, measured as those visible on the outer and upper surfaces of living Porites colonies, could be used as an bioindicator for water quality status, we examined its variation along water quality gradients in four regions of the inshore Great Barrier Reef. In each region, three reefs located at increasing distances to a river mouth were surveyed at two depths. The data show that in all four regions, internal macrobioeroder densities increased towards the river mouths, and with depth. Densities on reefs near the river mouths were twice those of the reefs at intermediate and far distances, whereas the latter two did not differ. Across regions, densities were related to the long-term mean turbidity at each reef. Macrobioeroder density increased by 19.8 and 11.6 bioeroders m^{-2} per unit NTU at deep and shallow sites, respectively. In contrast, the relationship to mean water column chlorophyll was weak. Our study showed that internal macrobioeroder density, as quantified by the density of bivalvia boreholes on the upper surface of living massive Porites, can indeed be used as a bioindicator measure for changing water clarity on the Great Barrier Reef where turbidity data are unavailable. It also shows that internal macrobioerosion, which weakens coral and substrata and makes them more susceptible to storm damage, is intense on some inshore reefs, with densities averaging 2,500 internal macroborers per square metre of coral surface on Wet Tropics reefs near the Tully River.

c. Contribution to research on seagrass communities and their responses to changing environmental conditions along the Queensland coast [QDPI&F]

We have conducted preliminary analysis of data collected in Task 1.1.3 and the intertidal seagrass component of Reef Rescue MMP. Analysis of epiphyte cover and epiphyte biomass data found a poor relationship. This appears to be primarily a consequence of the difficulty quantitatively sampling epiphyte biomass. Analysis and interpretation of mapping and monitoring data from Cooktown in the north to Hervey Bay in the south is continuing, with a focus on identifying physiological (plant tissue nutrient) and morphological measures and indicators of meadow resilience in response to changing water quality. Preliminary interpretation was presented in issue 35 of Seagrass-Watch News (www.seagrasswatch.org).

MTSRF Project 3.7.1 Objective (d): Estuarine indicators for ecosystem condition (Report 2 Submission)

Marcus Sheaves, Rod Connolly, Ross Johnston
19 February 2009

Task 1: Complete statistical analysis and model construction for Objective (d)

- Annual cycle of sampling (to March 2009) is on track for completion. However, if flooding has not subsided the final sampling event may not be possible.
- Laboratory sorting and recording, and preliminary statistical analyses of catches are up to date and final statistical analysis and model building is only awaiting March 2009 sampling.
- Preliminary analyses have allowed strong preliminary conclusions (see below) that only await the inclusion of last data for final validation.

Task 2: Commence work on evaluation studies for Objective (d)

Evaluation studies have been held up by flooding – working in estuaries is impossible during flood events. We expect to commence work on evaluation studies in the next three weeks as long as no further flooding occurs.

Task 3: Progress update for activities listed against Objective (d)

This study is developing appropriate approaches to the evaluation of estuarine ecosystem condition in a tropical Australian context, and has made substantial progress. The only major hold-up has been due to lost time caused by major flooding in early 2008 and 2009 in North Queensland.

Field sampling:

- The major (cast net) sampling of fish has been conducted as planned except for time lost early in 2008 and 2009 due to severe flooding. Completion of the annual cycle of sampling (to March 2009) is on track for completion. However, if flooding has not subsided the final sampling event may not be possible.
- Laboratory sorting and recording, and preliminary statistical analyses of catches are up to date and final statistical analysis and model building is only awaiting March 2009 sampling.
- Flooding also meant gill net catches had very narrow taxonomic compositions and added little data to that available from cast nets. Consequently, gill net sampling was curtailed to prevent needless destruction of a substantial biomass of fish.

Fish assemblage structure:

- Studies of fish assemblage structure over space and time will be completed when the final data is in. However, it is already clear that fish assemblage structure is not a useful absolute measure of estuary health in itself. Assemblage structures vary from estuary to estuary but variation is not predictable in terms of proximity, meaning it cannot be assumed that nearby estuaries can stand as appropriate controls for comparative studies. Moreover, assemblage structure and its simple surrogates (e.g. species richness) do not line up in a systematic way along a pristine-impact gradient, invalidating the expectation that community structure reflects health in a simple way. However, the temporal consistency of assemblage structure means that the ***location-specific variability in assemblage composition*** can provide a useful measure of estuary health.
- Additionally, studies of assemblage structure have provided a much greater understanding of the spatio-temporal organisation of tropical estuarine fish fauna allowing insights that do indicate potentially useful measures of estuary health, e.g. ***population structure of common estuary spawning fish***.

Trophic studies:

- Trophic understanding is well advanced for all the common components of the assemblage and final analysis is only waiting for the final samples to be collected. Once this is complete the full range of potentially useful trophic variables can be assessed.

Recruitment strength studies:

- Recruitment studies are underway but as this is the most time consuming data to analysis final results will not be available until towards the end of the project.

Stable isotope analyses:

- Stable isotope samples have all been collected and are currently undergoing chemical analysis.

Scavenging pressure:

- Scavenging studies showed systematic variability in levels of scavenging pressure. Because many animals are opportunistic scavengers, the potential for scavenging is driven by factors that also drive competition for food. More generally, the vigour of these trophic processes, which effectively shunt nutrition and biomass around food webs, are components of the vibrancy or health of the ecosystem. Consequently, scavenging pressure is included in the suite of measures to be included in evaluation studies.

Assessment of individual condition:

- Severe flooding in the two years interfered with the collection of *Lutjanus russellii* for the assessment of individual condition.

Overall outcomes to date:

- Preliminary studies of 9 estuaries provided a number of insights that provide considerable advances in the development of appropriate sampling and experimental strategies for evaluating estuarine ecosystem condition in the context of the unique ecological and physical attributes of north-eastern Australian estuaries. This has now been enhanced with the extra spatio-temporal data becoming available from MTSRF project itself.
- Summary measures (e.g. total abundance, species richness) usually used to assess ecosystem health in similar habitats show little relationship to impact status, except where health is extremely degraded. This means trying to develop them as absolute measures (e.g. in a report card framework) is rarely likely to be possible.
- Assemblage structures vary from estuary to estuary but variation is not predictable in terms of proximity, meaning it cannot be assumed that nearby estuaries can stand as appropriate controls for comparative studies.

- Consistent faunal patterns within individual estuaries over time indicate that a more appropriate approach for assessing environmental condition is to take advantage of this temporal consistency and use site-specific studies with the established pattern of change over time as the reference condition. Additionally, evaluation of long-term data sets indicates that location-specific variability in assemblage composition can provide a useful measure of estuary health, particularly where water quality stressors are involved.
- Clear seasonal changes mean that seasonality has to be factored in, with reference conditions needing to refer to particular points in time as well as to a specific estuary. This aspect will be addressed with the data currently being collected.
- Estuary specific faunal patterns and seasonal changes are very robust. This is seen in consistent seasonal change across sites and the maintenance of site specific faunal patterns, despite samples analysed so far coming from the high recruitment season and despite extreme seasonal flooding with the potential to flush fish from the small estuaries sampled. Consequently, it should be possible to define optimal times to conduct studies to assess estuary condition. This surprising consistency also indicates that there is great potential in developing the use of process-specific variables as measures of estuary condition.
- The study has emphasized the complex nature of tropical estuary fish fauna leading to the realization that there are particular components of the fauna (viz; common estuary spawning species) that are likely to provide sensitive, site-specific indicators of change in estuary health.
- One feature of the tropical estuarine fauna that is now clear is the primacy of habitat in structuring faunal composition. Consequently, if a healthy fauna is considered one that is in a “natural” state then habitat integrity is an important aspect of estuarine health. This means that the level of habitat change is an important measure of health.
- Successful scavenging pressure studies indicate it has considerable potential as a measure of ecosystem condition, particularly when combined with other estuary specific approaches.

Communications, major activities or events – During milestone reporting period

- K. Fabricius gave a WQ and Reef Atlas presentation at a JCU Mini-symposium on “Ecosystem Services of the GBR”, 9 February 2009.
- Completion of four publications and one thesis:
    - Humphrey, C, Weber M, Lott C, Cooper T, Fabricius KE (2008) Effects of different types of sediment, dissolved inorganic nutrients and salinity on fertilisation and embryo development in the coral *Acropora millepora*. *Coral Reefs* 27: 837-850.
    - Negri, A.P., Soo, R.M., Flores, F., Webster, N.S. (2009) *Bacillus* insecticides are not acutely harmful to corals and sponges. *Marine Ecology-Progress Series* (in press).
    - Cooper TF, Gilmour JP, Fabricius KE (in review) Coral-based bioindicators of changes in water quality on coastal coral reefs: A review and recommendations for monitoring programs. *Coral Reefs.*
    - De’ath G, Fabricius KE (in review) Water quality as regional driver of coral biodiversity and macroalgal cover on the Great Barrier Reef. *Ecological Applications.*

- Fabricius KE (in review) Factors determining the resilience of coral reefs to eutrophication: a review and conceptual model. In: Z Dubinski (ed): Corals and Coral Reefs. Springer.
- Altenrath, C (2009). Growth and photophysiological response of benthic symbiotic foraminifera along a nutrient gradient on the Great Barrier Reef. University of Cologne, pp 31