Cooper, Timothy F. (2008) ***Coral bioindicators of environmental conditions on coastal coral reefs.*** **PhD thesis, James Cook University.**

Coral bioindicators of environmental conditions on coastal coral reefs

Thesis submitted by
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in June 2008

for the degree of Doctor of Philosophy
in the School of Marine and Tropical Biology
James Cook University

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Chapter 2 is included without abstract and published as Cooper TF, Uthicke S, Humphrey C, Fabricius KE. (2007). Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Islands, central Great Barrier Reef. *Estuarine, Coastal and Shelf Science* 74: 458-470. The data was collected by all authors during field work undertaken over a 2-year period from 2004 to 2006. S Uthicke collected, processed and wrote the sediment sections. TF Cooper compiled and analysed the water quality and irradiance data, and wrote the manuscript. The manuscript (and this chapter) was submitted after editorial contributions from all co-authors.

Chapter 3 is included without abstract as Cooper TF, Ulstrup KE. (in review). Mesoscale variation in the photo-physiology of a coastal coral on the Great Barrier Reef. *Marine Biology*. TF Cooper collected and analysed the data, and wrote the manuscript. KE Ulstrup processed the data and derived parameters from the rapid light curves. The manuscript (and this chapter) was submitted after editorial contributions from the co-author.

Chapter 4 is included without abstract as Cooper TF, Slivkoff M. (in prep). Relationship among coral reflectance, chlorophyll *a* concentration and perceived brightness of scleractinian corals. TF Cooper collected and analysed the data, and wrote the manuscript. M Slivkoff processed the spectral reflectance data. TF Cooper and M Slivkoff designed and built the reflectance chamber. The manuscript (and this chapter) has been prepared after editorial contributions from the co-author.

Chapter 6 is included without abstract and published as Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE. (2008). Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. *Marine and Freshwater Research* 59: 703-716. TF Cooper collected and analysed the data. PV Ridd and C Humphrey assisted with logger deployment and processing of physical and water quality samples. KE Ulstrup assisted with processing of coral samples and M Slivkoff processed the satellite image. The manuscript (and this chapter) was submitted after editorial contributions from all co-authors.

Chapter 7 is included without abstract and published as Cooper TF, De'ath G, Fabricius KE, Lough JM. (2008). Declining coral calcification in massive *Porites* in two nearshore regions of the northern Great Barrier Reef. *Global Change Biology* 14: 529-538. The samples were collected by TF Cooper and KE Fabricius. TF Cooper processed the coral slices and wrote the manuscript. JM Lough supervised sample processing and extracted the growth variables from the coral slices. The statistical analyses were done by G De'ath. The manuscript (and this chapter) was submitted after editorial contributions from all co-authors.

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Publications

<u>Peer-reviewed journal articles associated with this thesis</u>

Cooper TF, Ulstrup KE. (in review). Mesoscale variation in the photo-physiology of a coastal coral on the Great Barrier Reef. *Marine Biology.*

Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE. (2008). Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. *Marine and Freshwater Research* 59: 703-716

Cooper TF, De'ath G, Fabricius KE, Lough JM. (2008). Declining coral calcification in massive *Porites* in two nearshore regions of the northern Great Barrier Reef. *Global Change Biology* 14: 529-538

Cooper TF, Uthicke S, Humphrey C, Fabricius KE. (2007). Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Islands, central Great Barrier Reef. *Estuarine, Coastal and Shelf Science* 74: 458-470

<u>Peer-reviewed journal articles relevant but not associated with this thesis</u>

Humphrey C, Weber M, Lott C, **Cooper TF**, Fabricius KE. (2008). Effects of different types of sediment, dissolved inorganic nutrients and salinity on fertilisation and embryo development in the coral *Acropora millepora* (Ehrenberg, 1834). *Coral Reefs* doi 10.1007/s00338-008-0408-1

Wolanski E, Fabricius KE, **Cooper TF**, Humphrey C. (2008). Wet season fine sediment dynamics on the inner shelf of the Great Barrier Reef. *Estuarine, Coastal and Shelf Science* 77: 755-762

Fabricius KE, De'ath G, Puotinen ML, Done TJ, **Cooper TF**, Burgess, SC. (2008). Disturbance gradients on inshore and offshore coral reefs caused by a severe tropical cyclone. *Limnology and Oceanography* 53: 690-704

<u>Conference abstracts</u>

Cooper TF, Slivkoff M, Fabricius KE. (2006). Coral colour responds to changes in water quality: validation of a bioindicator using reflectance spectrometry. International Society for Reef Studies: European Meeting, 19 – 22 September 2006, Bremen, Germany.

Conference abstracts contd.

Cooper TF, Slivkoff M, Fabricius KE. (2006). Coral colour responds to changes in water quality: validation of a bioindicator using reflectance spectrometry. Australian Marine Sciences Association, 9 – 13 July 2006, Cairns, Australia. *Ron Kenny Prize for Highly Commended student oral presentation.*

Cooper TF, Fabricius KE, Humphrey C, Neale S. (2005). Coral based indicators of the effects of water quality on nearshore reefs of the Great Barrier Reef. Rainforest meets Reef: Joint conference of CRC Reef and Rainforest CRC, 22 – 24 November 2005, Townsville, Australia.

“I thought of that while riding my bicycle”

— Albert Einstein, on the theory of relativity.

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ABSTRACT

Reversing the decline in water quality is a key priority for the protection of the Great Barrier Reef (GBR). Strategies to improve the water quality of the GBR include conservation of riparian zones and the adoption of ecologically sustainable practices in the catchments. The implementation of these strategies requires feedback to resource managers and the community through monitoring programmes aimed at detecting biological responses to changes in water quality. This thesis investigates a range of coral indicators at different spatial and temporal scales and identifies those most suitable for inclusion into a toolbox for monitoring the condition of coastal coral reefs on the GBR. The approach combines *in situ* studies of coral indicators in different regions and environmental gradients on the GBR with controlled manipulative experiments exposing corals to differing water quality to examine causality of correlations observed in the field.

An environmental gradient was identified in the Whitsunday Islands where water column variables (especially chlorophyll *a*, total suspended solids, particulate organic carbon and particulate nutrients) and irradiance variables (Secchi and optical depth) differed significantly from nearshore to the outer islands. For example, mean concentrations of chlorophyll *a* were up to 1.9 times greater at nearshore (Repulse Island; RI: 0.59 ± 0.12 µg L^{-1} mean ± SE) compared with outer islands (Edward Island; EI: 0.31 ± 0.06 µg L^{-1}) averaged over five sampling events from 2004 to 2006, whereas mean Secchi depth was approximately 3 times lower at nearshore (RI: 4.0 ± 0.8 m) than outer locations (EI: 15.3 ± 3.3 m). Some of the coral indicators showed significant relationships with a water quality index (WQI) derived for the Whitsunday Islands. Responses of photo-physiological measures of *Symbiodinium* associated with *Pocillopora damicornis* along the gradient were consistent with patterns of light acclimatisation and suggested deep corals (i.e. below 5 – 6 m depth) on nearshore reefs in the Whitsunday Islands are light-limited. Both colony brightness and tissue thickness of massive *Porites* spp., and the maximum depth of reef building corals, increased from nearshore to outer locations along the gradient. Similarly, a 50-fold decrease in the density of macro-bioeroders in massive *Porites* from nearshore to outer locations was indicative of increased particle loads on the nearshore reefs. The data of the maximum depth limit for coral reef development at locations where suitable settlement substrata were available suggest that the absolute minimum of light required for a coral reef to persist is in the range of 6 – 8 % of surface irradiance in the Whitsunday Islands.

The model that color brightness of corals responded to changes in water quality was validated with manipulative experiments in the laboratory and by transplantation of small nubbins along the environmental gradient. The experiments showed nubbins of massive *Porites* became darker, i.e. concentrations of pigments increased, within 20 – 40 days of exposure to elevated nutrients and

reduced irradiances compared with corals kept in filtered sea water and unshaded conditions. The response in colony brightness was consistent with other studies of photo-acclimatisation to enhanced nutrients and light limitation. However, a 2.5-fold decrease in symbiont density of *P. damicornis* during the wet compared with the dry season, which in turn influenced colony brightness, was related strongly to seasonal changes in sea surface temperature (SST). Thus, effects of seasonal variation of a range of environmental parameters need to be considered if physiological measures such as colony brightness are used in water quality monitoring programmes.

The simultaneous *in situ* measurement of benthic irradiance and turbidity at a shallow depth (~3.5 m) on a coastal coral reef for 2 years allowed the quantification of potential thresholds of concern for turbidity. The linear relationship between the attenuation coefficient for downward irradiance K_d (PAR) and turbidity showed that a change from 0 to 3 nephelometric turbidity units (NTU) at 3.5 m results in a decrease of 88% of benthic irradiance to levels around 200 µmol photons m^{-2} s^{-1}. The minimum saturating irradiance (E_k) of *Symbiodinium* associated with *P. damicornis* was approximately 206 ± 8 µmol photons m^{-2} s^{-1} at shallow depths on nearshore reefs of the Whitsunday Islands. Thus, levels of turbidity greater than 3 NTU can result in environmental conditions that are light limiting, and hence sublethal photo-physiological stress, for *P. damicornis*. Levels of turbidity of 4.5 NTU corresponded to 6 – 8% of surface irradiance, which was a critical level of irradiance required for coral reef development in the Whitsunday Islands. Thus, long-term turbidity >3 NTU could be used as a threshold of turbidity for sublethal photo-physiological stress, while long-term turbidity >5 NTU for severe stress effects on *P. damicornis* at shallow depths (~3.5 m) on coastal reefs.

Temporal variation in the growth parameters of massive *Porites* from two nearshore regions of the GBR were not consistent with regional differences in water quality. Mean annual SST increased by ~0.38°C over a 16 year study period that correlated with a decline of ~21% in coral calcification rates. A decline in calcification of this magnitude with increasing SST contrasts with results of previous studies and is unprecedented in recent centuries. Changes in the growth parameters were linear over time, while SST had no effect on skeletal density, but a modal effect on annual extension and calcification with maxima at ~26.7°C. The findings were consistent with other experimental studies of the synergistic effect of elevated seawater temperatures and CO_2 partial pressure (pCO_2) on coral calcification and suggest that monitoring of seawater chemistry should be undertaken on the GBR.

Defining a set of key selection criteria and assessing the characteristics of candidate indicators in a matrix against changes in water quality, allowed the identification of coral indicators for a monitoring toolbox. The most suitable bioindicators were: symbiont photo-physiology, colony brightness, skeletal and tissue growth, and bioeroder density in massive *Porites*, coral recruitment, community structure of corals, indicator organisms other than corals and the maximum depth of coral reef development. As each of these measures has a different sensitivity and response time to changes in environmental conditions, a combination of measures, i.e. a composite indicator system, is recommended for use in assessments of the condition of coastal reefs on the GBR.