# Kimberley Marine Research Program

*WAMSI Project 1.3.2*

## *Resilience of Kimberley coral reefs to climate and environmental extremes: past, present and future*

**The overall objectives of this project are to understand how corals, the key ecosystem engineers on tropical reefs, have adapted and will respond in the future to the extreme variations in physical and chemical conditions that are characteristic of the Kimberley coastal region.**

### Background

The Kimberley region in northwest Australia is a naturally extreme environment that features abundant and highly diverse coral reefs. However, it is not known how Kimberley corals can cope with these extreme conditions and whether this affects their calcification rates and resistance to climate and environmental change.

### Research Objectives

The overall objectives of this project are to understand how corals, the key ecosystem engineers on tropical reefs, have adapted and will respond in the future to the extreme variations in physical (e.g. light, temperature, water motion) and chemical (e.g. $pCO_2$, oxygen, and nutrients) conditions characteristic of the Kimberley coastal region.

Through a series of field and laboratory experiments, we aimed to:

1. Study seasonal **calcification rates** of common Kimberley corals over two years;
2. Assess their **thermal tolerance** and establish the first **bleaching thresholds** for this region; and
3. Reconstruct their **resilience to historical climate and environmental extremes** using geochemical proxies in coral cores.

*Aerial view of a bleached inshore Kimberley reef in April 2016. (Steeve Comeau)*

### The Approach

#### *1. Present day calcification rates on seasonal time scales*

Calcification rates of the common Kimberley corals *Acropora aspera* (branching), *Dipsastraea favus* (massive) and *Trachyphyllia geoffroyi* (massive) were studied from April 2011 through September 2012 in Cygnet Bay, spanning two winters and one summer.

Three experimental sites with varying degrees of tidal influence were chosen to assess the broadest range of light and temperature variability.

To compare the calcification rates of Kimberley corals with similar genera from a more typical tropical reef, a comparative study was conducted at Coral Bay in the southern part of the Ningaloo Reef Tract.

Calcification rates of *Acropora muricata* (branching), *Dipsastraea favus* (massive) and *Lobophyllia hemprichii* (massive) from a back-reef site were measured over the same time period as for the Kimberley corals.

#### *2. Thermal tolerance and bleaching thresholds of Kimberley corals*

In April/May 2014, a controlled experiment was conducted to assess the thermal tolerance and bleaching thresholds of two common Kimberley corals at the Kimberley Marine Research Station in Cygnet Bay.

Branching *Acropora aspera* and massive *Dipsastraea* sp. corals were collected from a tide pool and a subtidal environment, respectively. They were maintained in shaded outdoor flow-through mini-flumes at ambient +2°C and ambient +3°C temperatures for 11 days. A daily temperature variation of 4-5°C

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## *WAMSI Project 1.3.2 Calcification*

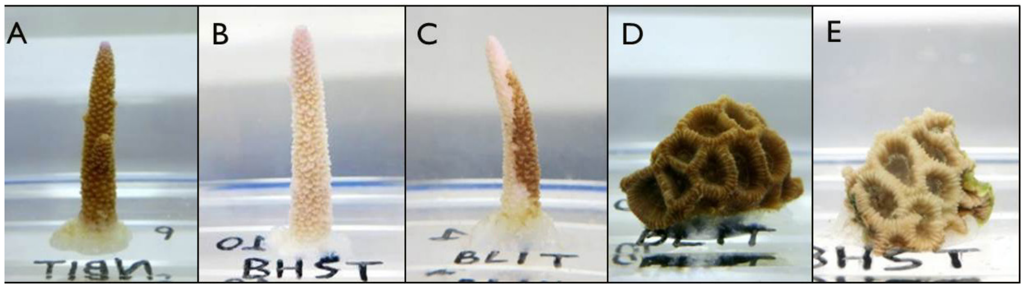


*Figure 2. (A) Healthy, (B) bleached and (C) partially dead Acropora aspera corals. (D) Healthy and (E) bleached Dipsastraea corals. (Verena Schoepf)*

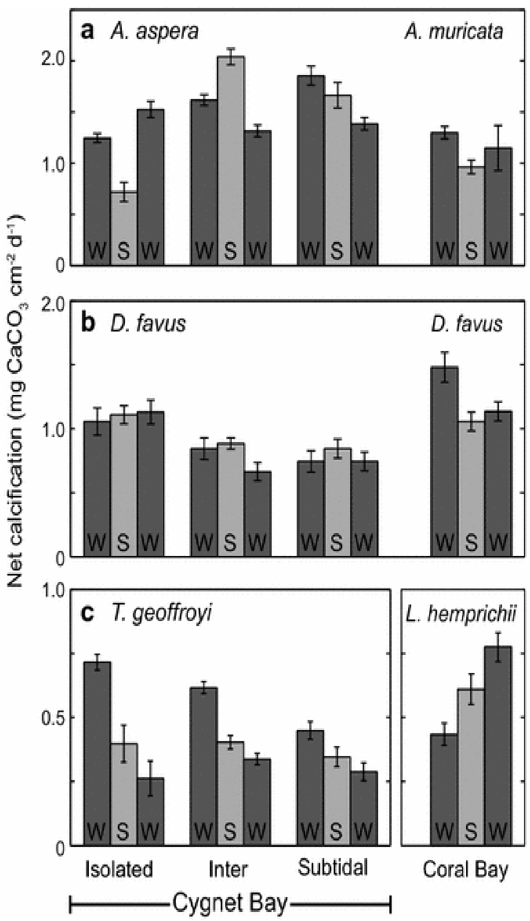


*Figure 1. Average net calcification rates (±SE) for (a) Acropora aspera and Acropora muricata, (b) Dipsastraea favus and (c) Trachyphyllia geoffroyi and Lobophyllia hemprichii over summer (September to March) and winter (March or April to September) at sites at Cygnet Bay in the Kimberley and at Coral Bay along Ningaloo Reef from April 2011 to September 2012. From Dandan et al. (2015).*

characteristic of intertidal habitats was simulated in all treatments. Seawater temperature, salinity, carbonate chemistry, and nutrients were monitored on a regular basis.

***3. Historic records from coral cores***

Using massive long-lived (50 -100 years) *Porites* colonies, it is possible to obtain long-term records of both climate and environmental change using preserved geochemical characteristics to quantify changes in seawater temperature (Sr/Ca, Li/Mg), pH (boron isotopes), salinity (oxygen isotopes and Sr/Ca), terrestrial runoff (Ba/Ca) and other parameters Similarly, long-term coral calcification rates can be reconstructed from a combination of the annual linear extension rate and density.

In April 2016, a ~1.2m-long coral core was collected from a massive *Porites* spp. colony in the subtidal zone of Shell Island near Cygnet Bay, of which the skeletal growth covers the calendar years from 1919 to 2015. High-resolution and annually-resolved geochemical measurements were conducted at the Advanced Geochemical Facility for Indian Ocean Research at UWA.

## Outcomes

***1. Present day calcification rates on seasonal time scales***

Despite experiencing more extreme environmental conditions, common Kimberley corals overall calcified at rates that were comparable or faster than those from similar corals at a more typical tropical reef, namely Ningaloo Reef located ~1200 km southwest of Cygnet Bay. The effects of tidal exposure and season, however, were highly species-specific: branching *A. aspera* grew more slowly in the environmentally more extreme intertidal than in the subtidal, whereas massive *D. favus* and *T. geoffroyi* grew faster in the intertidal environment.

Growth rates of branching *A. aspera* were reduced in summer compared to winter, suggesting that the combination of high summer temperatures and environmental extremes due to the large tidal amplitude resulted in an atypical seasonal behaviour (Fig. 1a). In contrast, the massive corals showed either no seasonal response or a more complex behaviour (Fig. 1b, c).

***2. Thermal tolerance and bleaching thresholds of Kimberley corals***

Detailed physiological measurements showed that Kimberley corals are highly susceptible to heat stress and coral bleaching despite being adapted to a naturally extreme temperature environment. The earliest onset of bleaching (i.e. chronic photoinhibition resulting in significant decreases in Fv/Fm) already occurred when corals were exposed to heat stress for only a few days and the first visible paling was observed after only 3-5 days (Fig. 2).

In the branching *Acropora* corals, exposure to heat stress corresponding to ~20 degree heating days resulted in up to 75% mortality or severe losses of symbiont cells and chlorophyll a per surface area in the surviving corals.

In contrast, massive *Dipsastraea* corals also experienced significant loss of symbiont cells and chlorophyll a, but all corals survived and losses were not as pronounced as in *Acropora*.

Based on these results, our best estimate of a coral bleaching threshold for Kimberley corals is ~32°C average daily temperature for only a few days, which is only ~1°C higher than maximum monthly mean (MMM) temperatures.

Overall, this confirms that corals already tolerant of naturally higher and more variable temperature environments are nonetheless living precariously close to their physiological limits for enduring thermal stress and that the upper thresholds for coral bleaching and survival are remarkably consistent at 1-3°C above regional MMM, regardless of location.

Importantly, intertidal corals of both species were generally more resistant to heat stress than the subtidal corals.

Since all corals harboured the same genetic type of *Symbiodinium* (clade C) independent of origin or treatment, this indicates that the native thermal environment plays a critical role in shaping coral thermal tolerance.

Specifically, the highly fluctuating intertidal environment (up to 7°C daily temperature variation) promotes greater resistance to heat stress than the more moderate subtidal environment (2-3°C daily temperature variation.

These findings were confirmed during the first documented, regional-scale bleaching event in the Kimberley region in March/ April 2016.

We conducted aerial bleaching surveys of ~30 reefs between Montgomery Reef and Sunday Island which were ground-truthed using in situ surveys. Most surveyed reefs had 30-60% bleaching and these data contributed to an Australia-wide analysis of the 2016 bleaching event.

At Shell Island, bleaching was more severe and widespread in the subtidal than the intertidal. Consequently, six months later this had resulted in dramatic mortality of branching *Acropora* corals, whereas most corals in the intertidal zone had recovered.

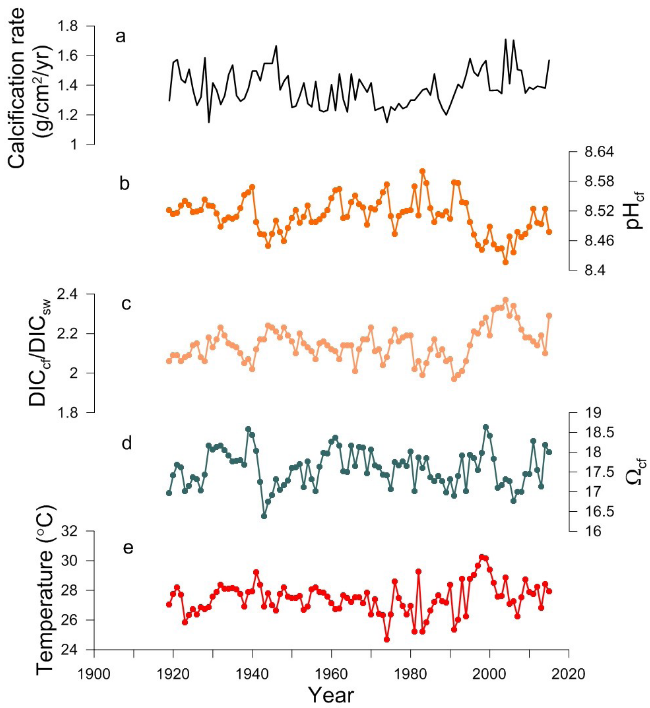


*Fig. 3 Annual variations in carbonate chemistry of the coral calcifying fluid and seawater temperature estimated from geochemical records for Porites coral from the Kimberley region: a, calcification rate; b, pH of the calcifying fluid ($pH_{cf}$); c, ratio of dissolved inorganic carbon (DIC) of the calcifying fluid versus seawater ($DIC_{cf}/DIC_{sw}$); d, aragonite saturation state of the calcifying fluid ($\Omega_{cf}$); e, seawater temperature.*

Although this natural bleaching event represents a major disturbance, chances for reef recovery are good given the absence of many other stressors in the Kimberley.

### *3. Historic records from coral cores*

The calcification rates of massive *Porites* spp. coral were relatively stable (~1.2 to ~1.6 g/cm²/yr) for the past ~100 years (Fig. 3a).

No significant trend was observed, despite a slight warming trend in the reconstructed annually-resolved seawater temperatures since 1919 and more variable temperatures since the 1970s (Fig. 3e).

The findings demonstrate that key calcification mechanisms in Kimberley corals are not compromised by the extreme environmental conditions, resulting in high and stable calcification rates as observed in corals from less extreme reef environments.

Nevertheless, recent ocean warming between 2011 and 2016 has negatively affected the critical relationship between coral algal symbionts and the animal host, which not only threatens calcification rates but also coral reef survival, as the natural bleaching event in summer 2016 demonstrated.

## What we found

Our findings to date show that:

1. Kimberley corals calcify at rates comparable to those from similar corals living in more typical tropical reefs.
2. Kimberley corals are as susceptible as other corals to unusual heat stress and bleaching, despite their remarkable ability to withstand temperature extremes over short time scales; findings that were confirmed during the first documented, regional-scale bleaching event in the Kimberley in summer 2016; and

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3. The calcification rate of Kimberley corals has kept at a relatively stable level for the past ~100 years, which is achieved by their ability to manipulate the carbonate chemistry in the calcifying fluid to cope with changes in seawater pH and temperature. A recent warming trend has created additional stress that is leading to a breakdown in the interactions between endosymbionts and the coral host and disrupting the ability of corals to calcify.

### Who will use this information?

This research is highly relevant to the natural resource management agencies in WA. The present-day seasonal and historical coral calcification rates measured here provide an important baseline and thus the basis for evaluating how coral growth responds to changes environmental conditions.

The first estimate of an experimentally based bleaching threshold for this region is of critical importance during times where heat stress events are increasing in frequency.

Coral health surveys conducted before, during and after the first natural bleaching event in the Kimberley region in 2016 provide important baseline data on coral bleaching abundance, bleaching susceptibility, and coral community dynamics associated with disturbance-related recovery and mortality.

### Type of data collected

Data produced in this project include a range of coral physiological and genetic data, physico-chemical seawater data and coral skeletal geochemical data.

### Data available in:

The metadata associated with this project will be able to viewed via the AODN metadata catalogue. Data will be available via Pawsey after the completion of the embargo period for the project.

### Project Team

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### Project webpage:

www.wamsi.org.au/calcification

*Bleached and dead staghorn coral exposed at low tide near Cygnet Bay, Kimberley, in April 2016. (Chris Cornwall)*

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