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The long-term drivers of environmental change in King Sound, Kimberley: the coral records

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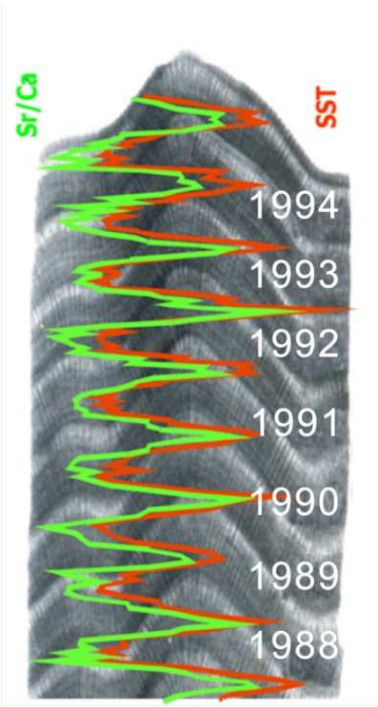
Massive Corals- paleoclimate archive



- **Widely distributed**
- **High growth rate (10-20 mm/yr, high resolution records)**
- **Accurately dated by either growth banding or U-Th geochemistry**
- **Richest paleoclimate archives**

Sr/Ca
Li/Mg
Ba/Ca
$\delta^{13}C$
$\delta^{18}O$
$\delta^{11}B$
B/Ca
……

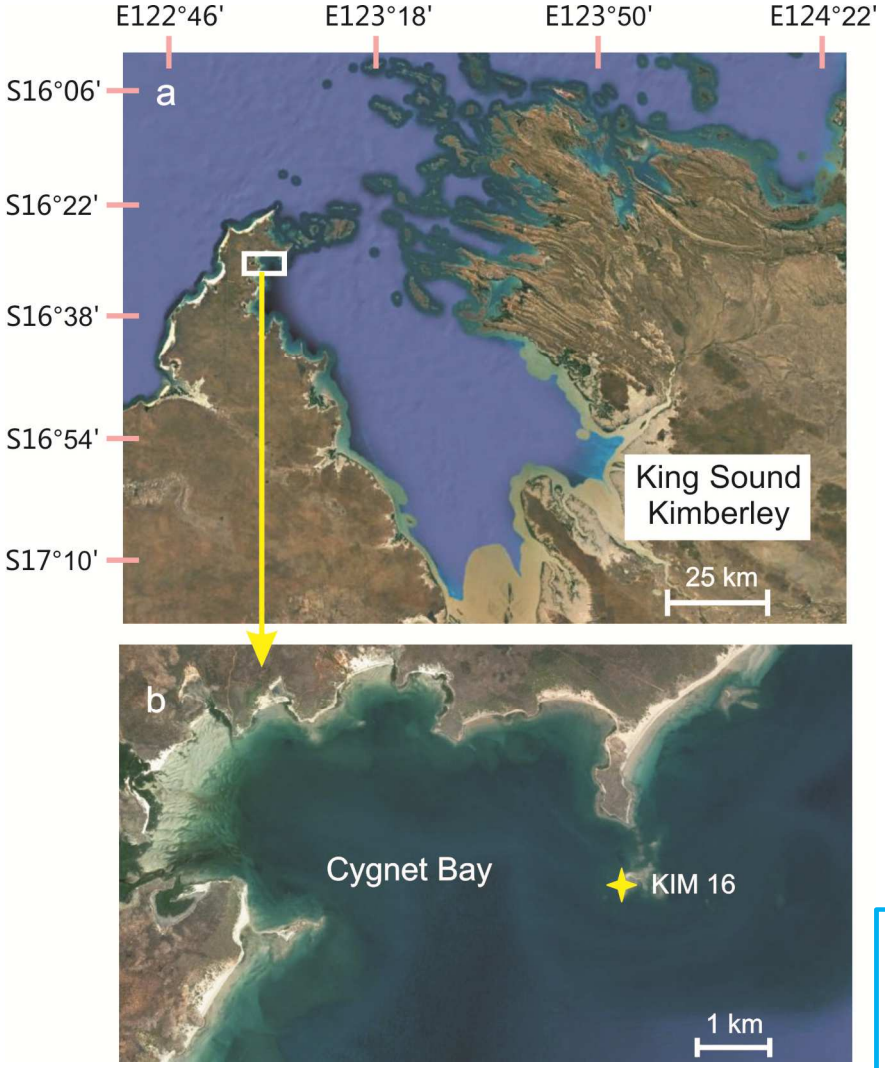
→

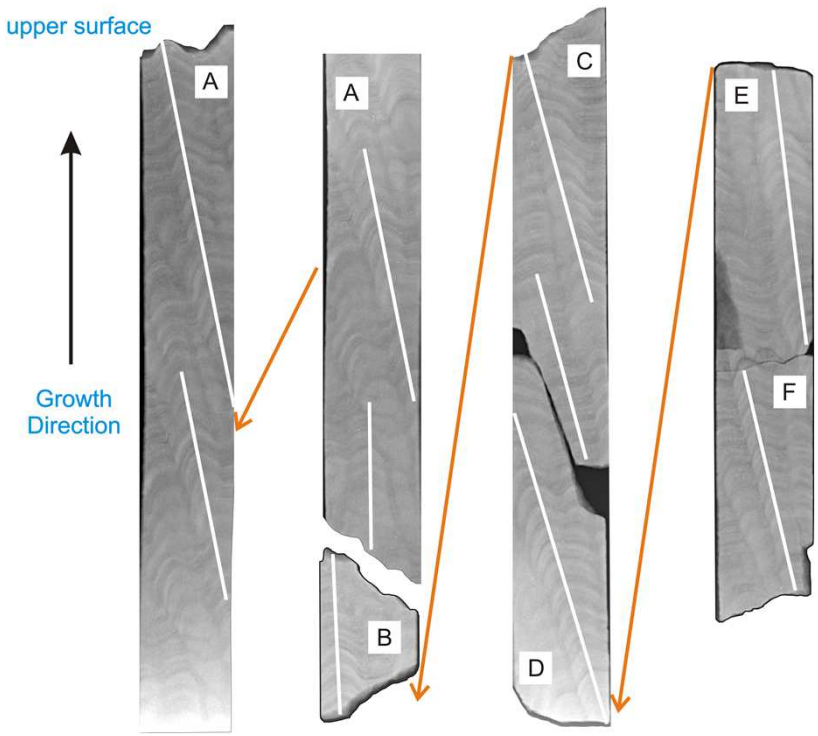
SST
rainfall
salinity
DICcf
pHcf
……

→

Paleoclimate
climate change
Coral calcification
Coral resilience
……

Coral core- from Cygnet Bay, King Sound





- ✓ **High-resolution samples: 2015-1995**
- ✓ **Annually-resolved samples: 2015-1919**

- ➢ **Temperature proxies: Sr/Ca, Li/Mg**
- ➢ **Calcification proxies: $\delta^{11}B$, B/Ca**
- ➢ **Terrestrial proxies: Ba/Ca, $\Delta\delta^{18}O$**

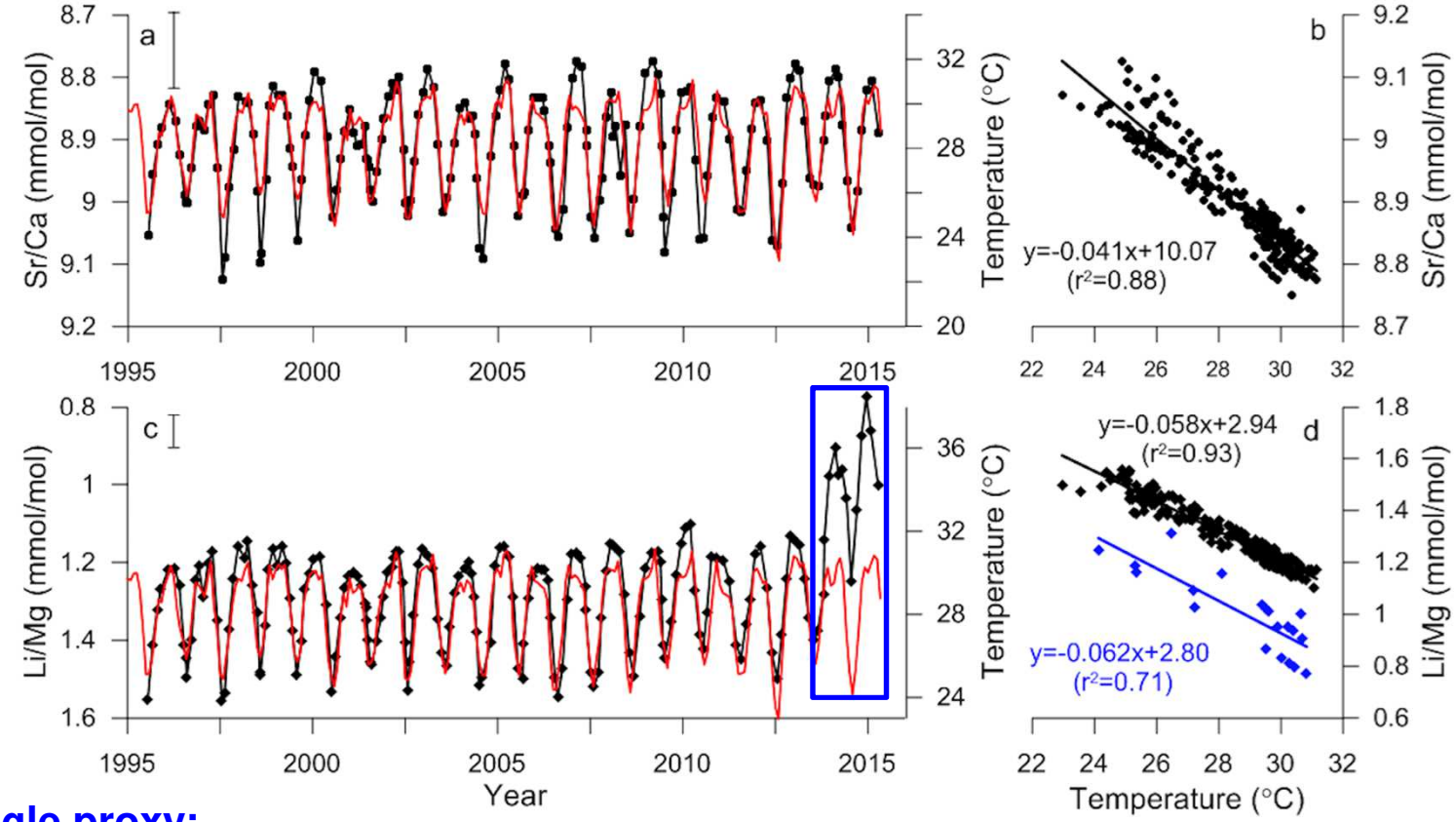
Outline

- ❑ Temperature reconstruction
- ❑ Coral calcification
- ❑ Fitzroy river influences on reef water

Part I

Temperature reconstruction

Sr/Ca- & Li/Mg-SST Calibrations



Single proxy:

Sr/Ca (mmol/mol) = – 0.041×T (℃)+ 10.07

Li/Mg (mmol/mol)= – 0.058×T (℃)+ 2.94 (before 2014)

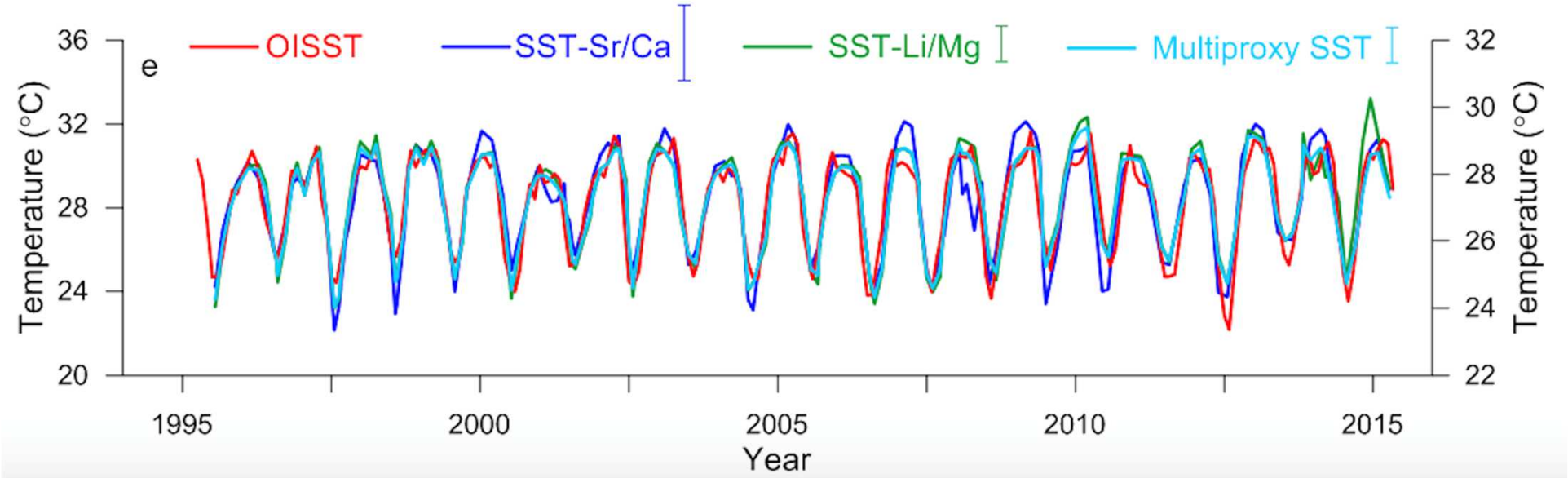
Li/Mg (mmol/mol)= – 0.062×T (℃)+ 2.80 (after 2014)

Multiproxy:

SST (°C) = –4.24×Sr/Ca (mmol/mol) – 13.38×Li/Mg (mmol/mol) + 83.46 (before 2014)

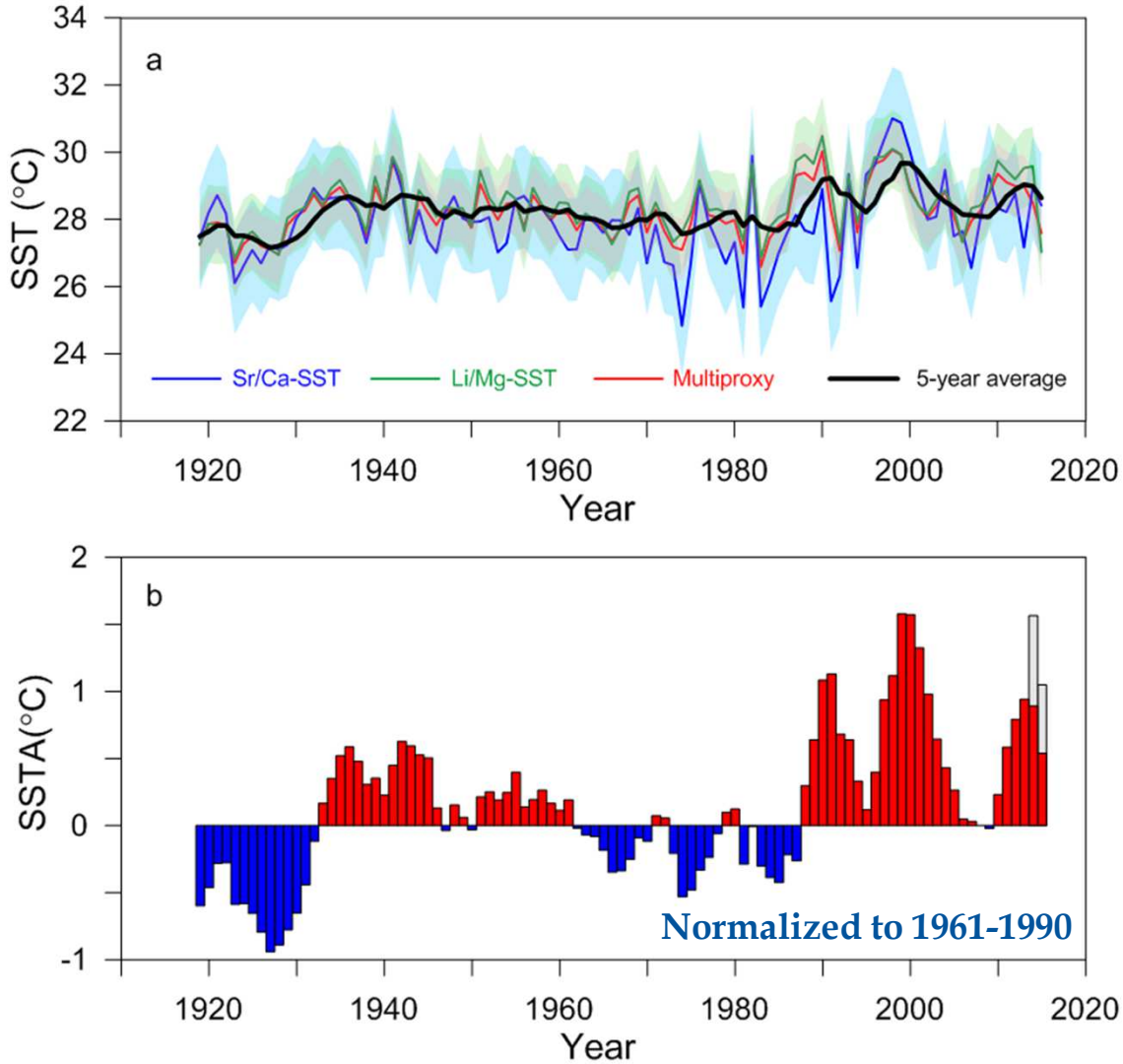
Sr/Ca- & Li/Mg-SST Calibrations

Linear Me/Ca-SST relationship



Reliable SST reconstruction under naturally extreme environment

Annual SST reconstruction



- Multiproxy calibrations provide a better temperature uncertainty;
- Average annual temperature of 28.2°C
- Long-term trend towards warming
- Positive anomalies (as high as 1.5 °C) and highly fluctuated temperature in recent decades
- Intensified thermal stress

Part II

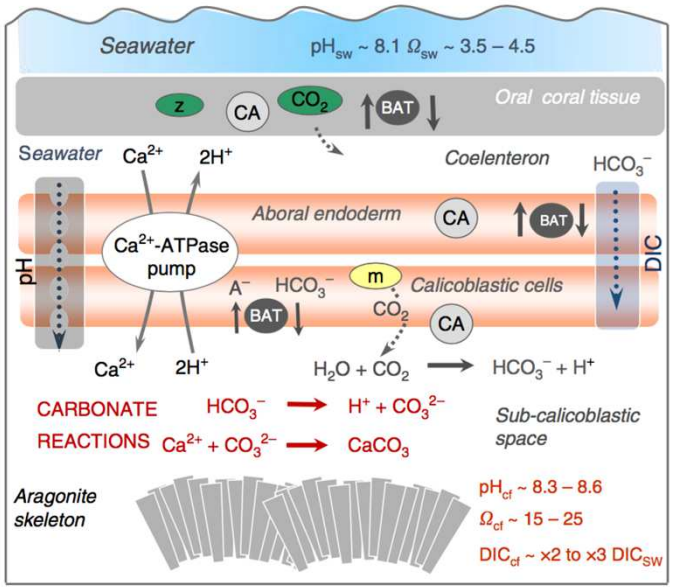
Coral Calcification

Coral Calcification

Calcification rate (g/cm²/yr)

Density (g/cm³) × Linear extension (cm/yr)

Carbonate chemistry of the coral calcifying fluid



(Holcomb et al., 2016; McCulloch et al., 2017)

- Calcifying fluid pH (pH_{cf}) – **skeletal $\delta^{11}B_{carb}$**

$$pH_{cf} = pK_B - \log\left[\frac{(\delta^{11}B_{sw} - \delta^{11}B_{carb})}{(\alpha_{(B3-B4)}\delta^{11}B_{carb} - \delta^{11}B_{sw} + 1,000(\alpha_{(B3-B4)} - 1))}\right]$$

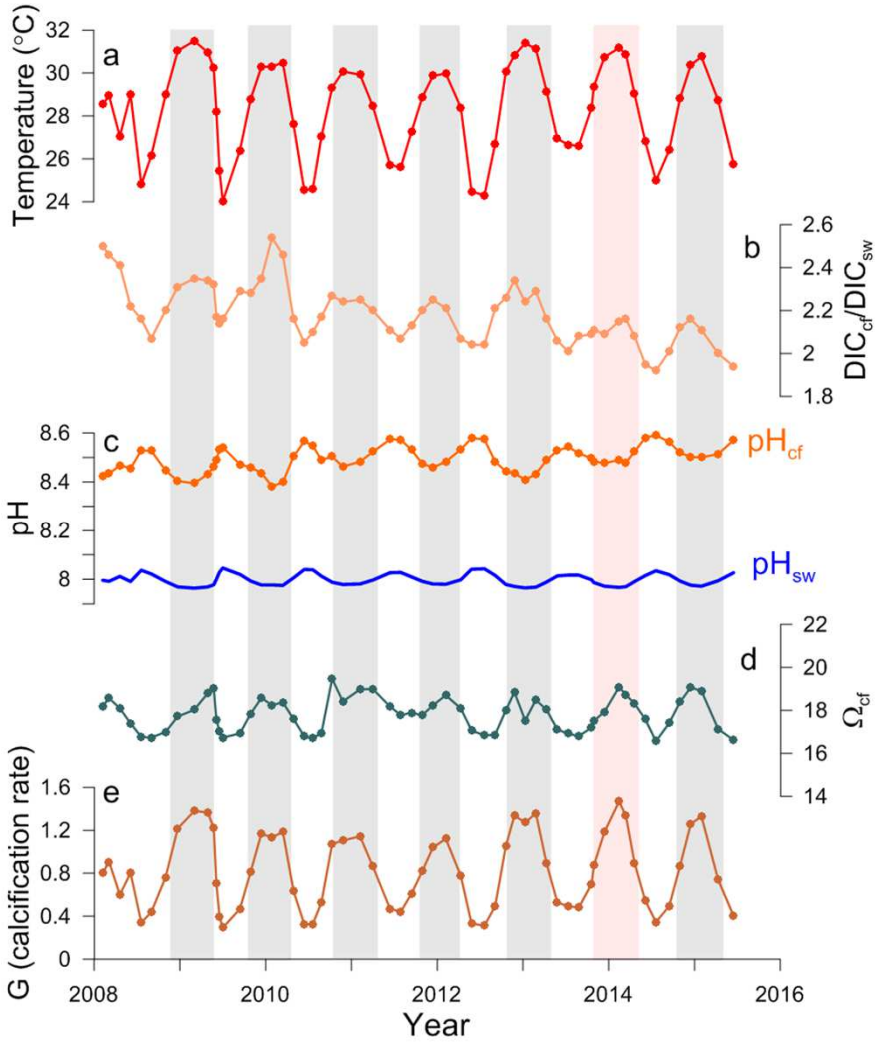
- Calcifying fluid DICcf – **skeletal B/Ca ratios**

$$[CO_3^{2-}]_{cf} = K_D \times [B(OH)_4^-]_{cf} / (B/Ca)_{CaCO_3}$$

$$K_D = 0.00297\exp(-0.0202\ [H^+]_T$$

$$[CO_3^{2-}] = \frac{DIC}{1 + \frac{[H^+]^2}{K_1' K_2'} + \frac{[H^+]}{K_2'}}$$

Carbonate chemistry in coral calcifying fluid

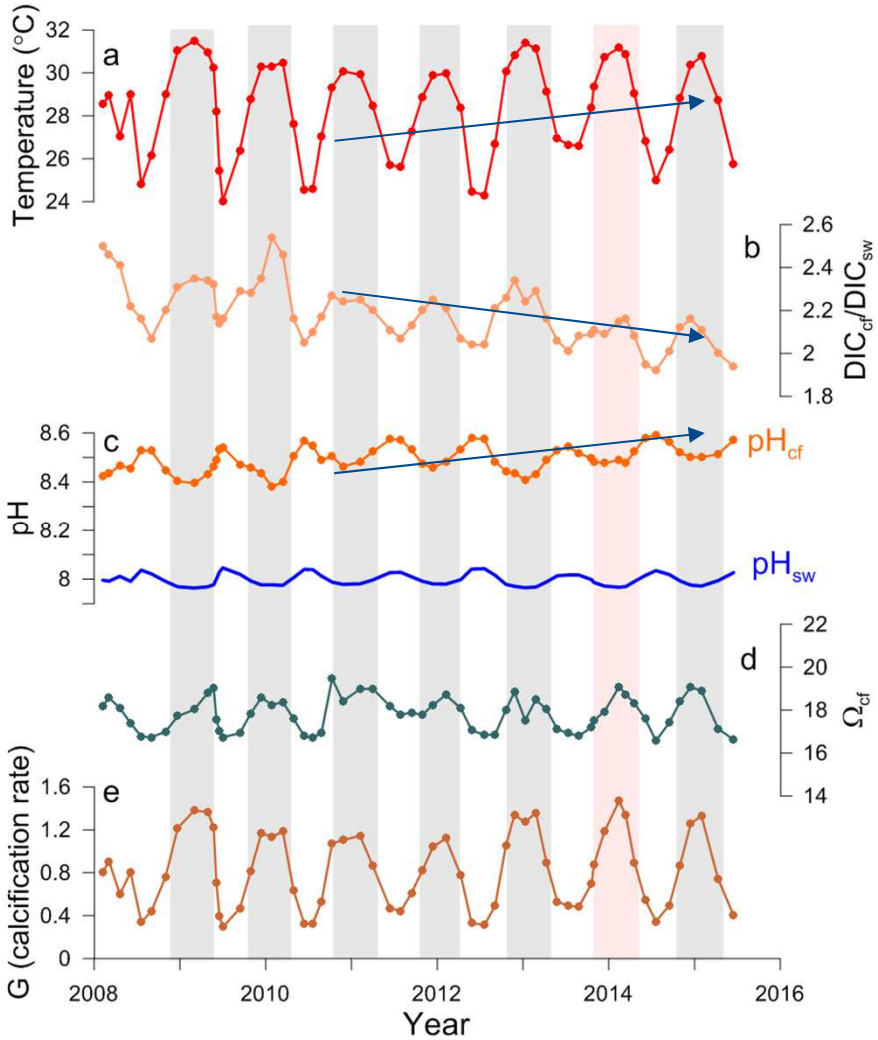


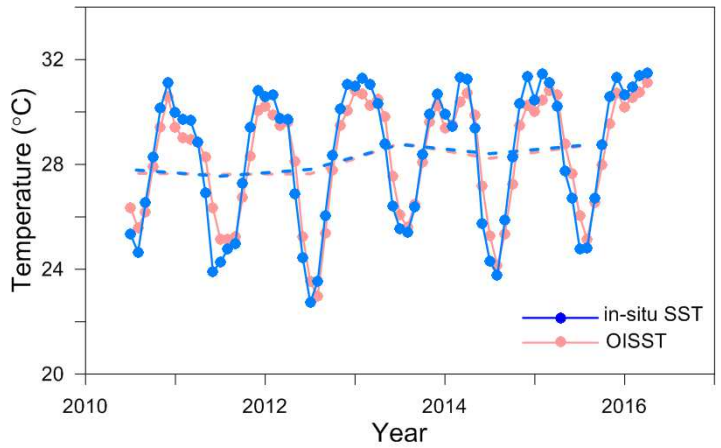
- **Up-regulated DICcf and pHcf**
  DICcf :~×2 Seawater DIC
  pHcf: ~0.5 above seawater pH
  Ωcf: 16-20, ×5~6 Seawater Ω

$$\Omega_{cf} = \frac{\left[Ca^{2+}\right]_{cf}\left[DIC\right]_{cf}}{K_{ar} \times \left\{1 + \frac{\left[H^{+}\right]}{K_2^*} + \frac{\left[H^{+}\right]^2}{K_1^* K_2^*}\right\}}$$

- **Typical seasonal cycles**
  DICcf、 Ωcf: higher in summer
  lower in winter
  pHcf: higher in winter
  lower in summer

Carbonate chemistry in coral calcifying fluid





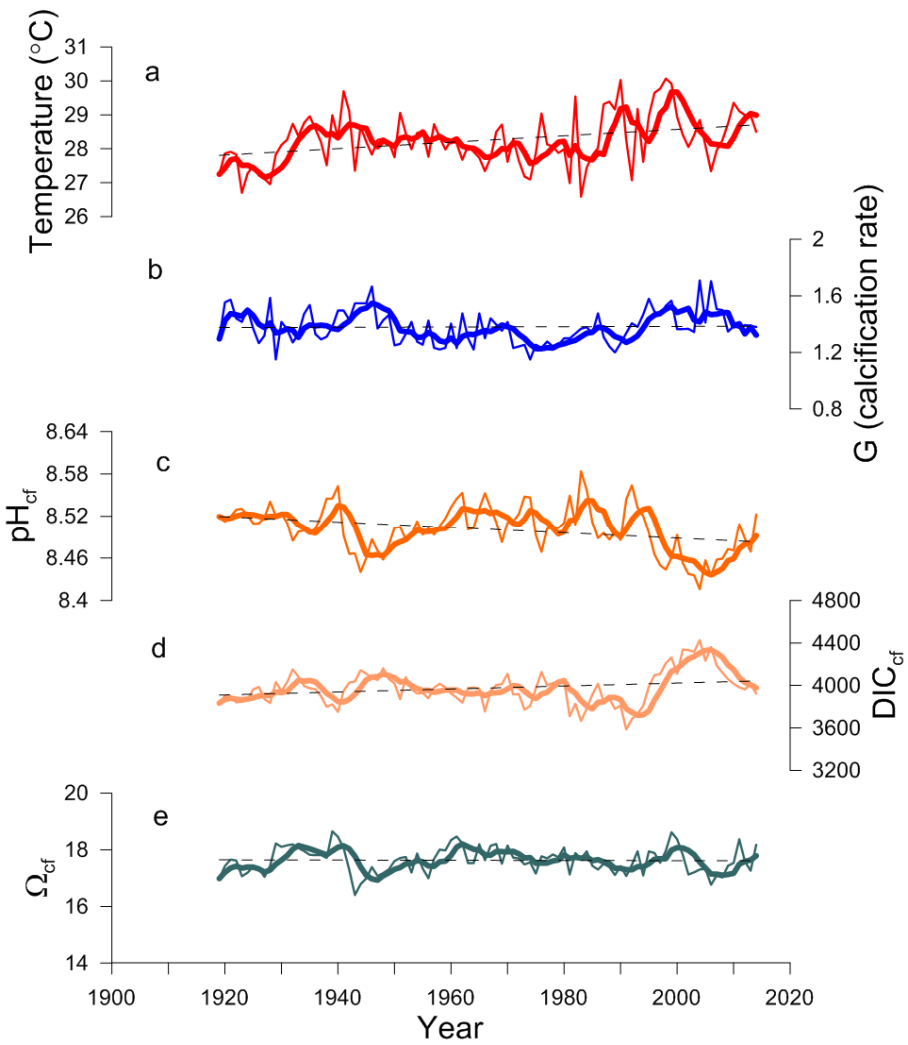
- **Thermal stress**

  Decreased DICcf and subdued variability

  Slightly increased pHcf

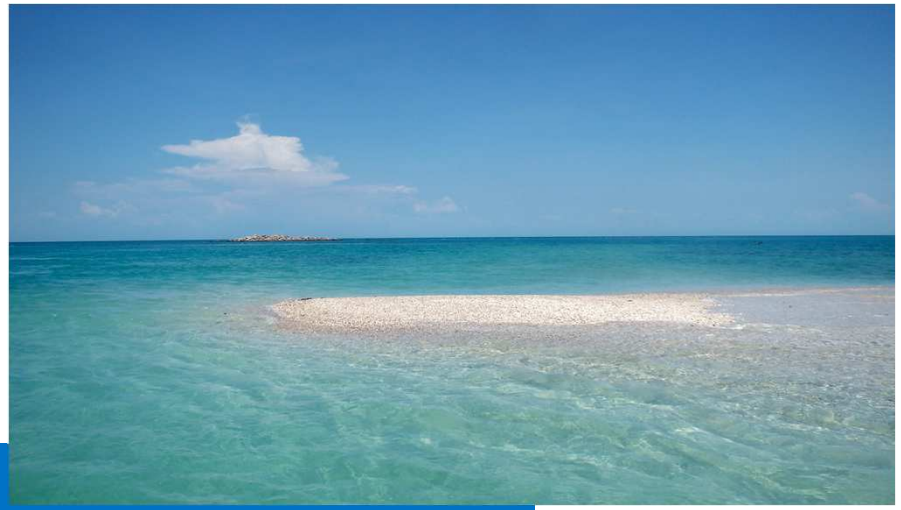
  Unaffected Ωcf

Carbonate chemistry in coral calcifying fluid



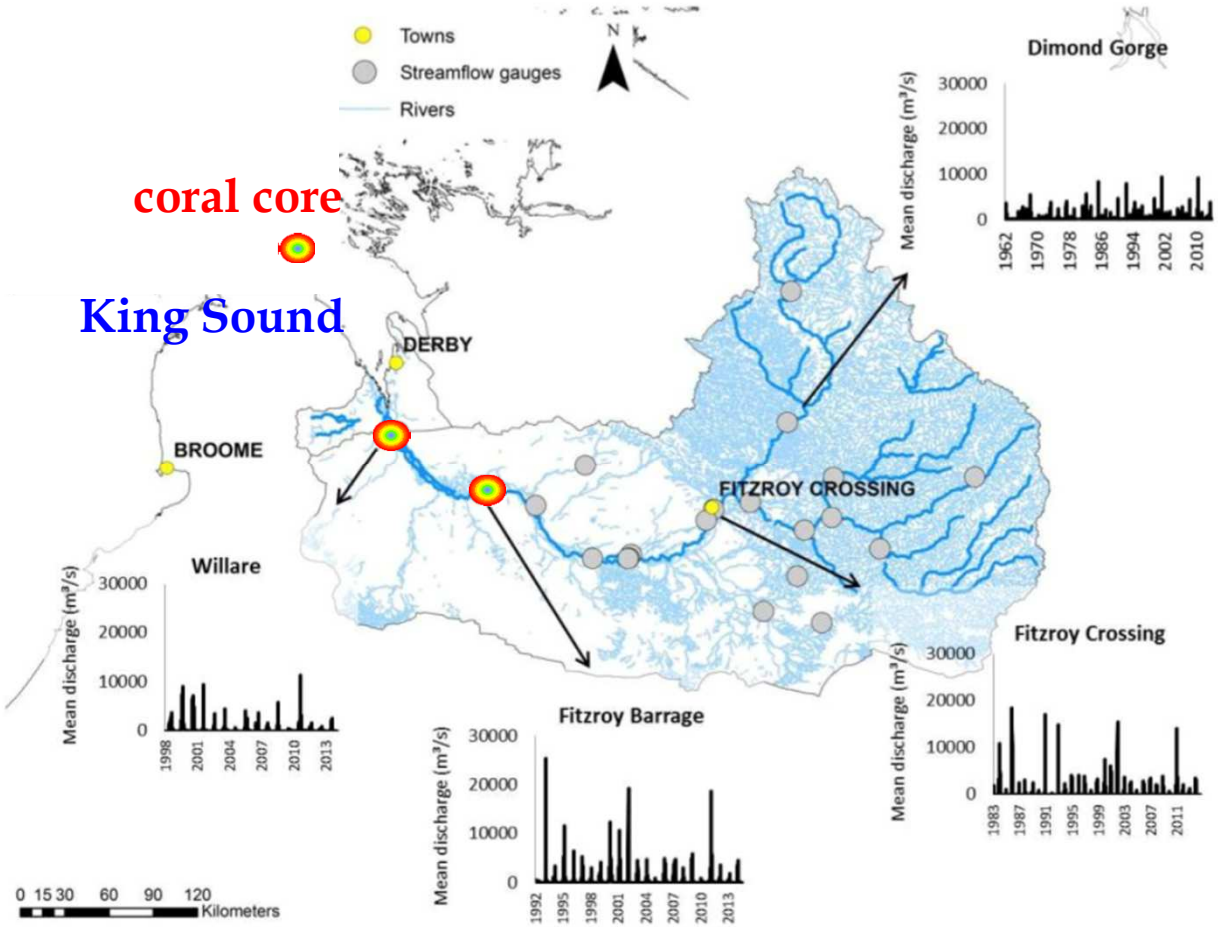
- **Relatively stable variation of calcification rate**: 1.2 - 1.6g/cm^2/yr
- **No significant trend was observed for calcification rate**
- **Antithetical long-term trends in pHcf and DICcf, result in relatively stable variation of Ωcf**

Part III



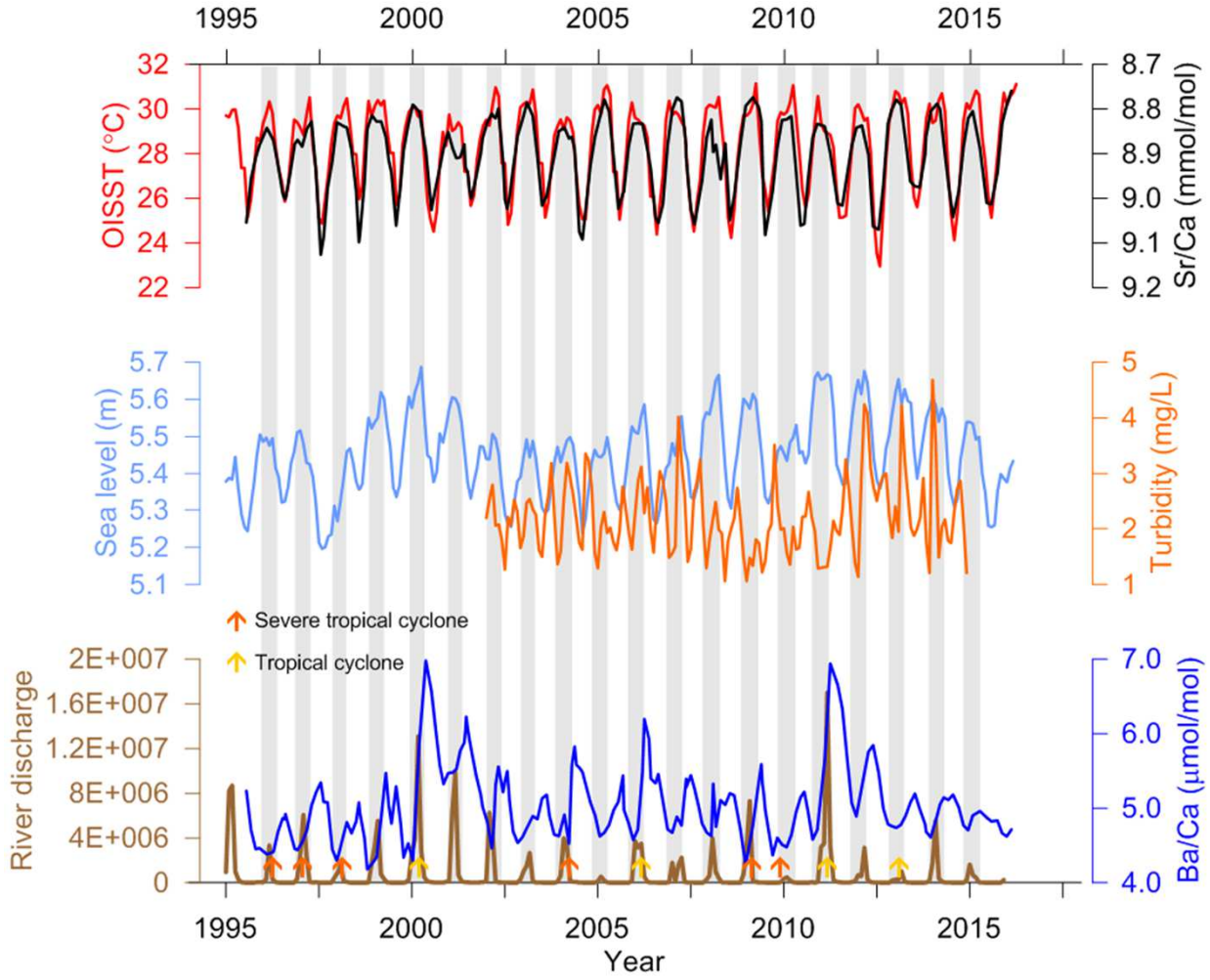
Runoff influences on reef water

Fitzroy River in Kimberley region



(Pusey&Kath, 2015)

River input to reef water



- Seasonal peaks in skeletal Ba/Ca
- 1-3 months lag between Ba/Ca and discharge peaks

Take-home Message

- ✓ The King Sound has experienced a long-term warming for the past century, and is undergoing intensified thermal stress in recent years.
- ✓ Key calcification mechanisms for the Kimberley corals are not compromised by the extreme environmental condition, resulting in high and stable calcification rates as observed in corals from less extreme reef environments.
- ✓ Recent ocean warming between 2011 and 2016 has negatively affected the critical relationship between coral algal symbionts and the animal host.

Thanks for your attention!

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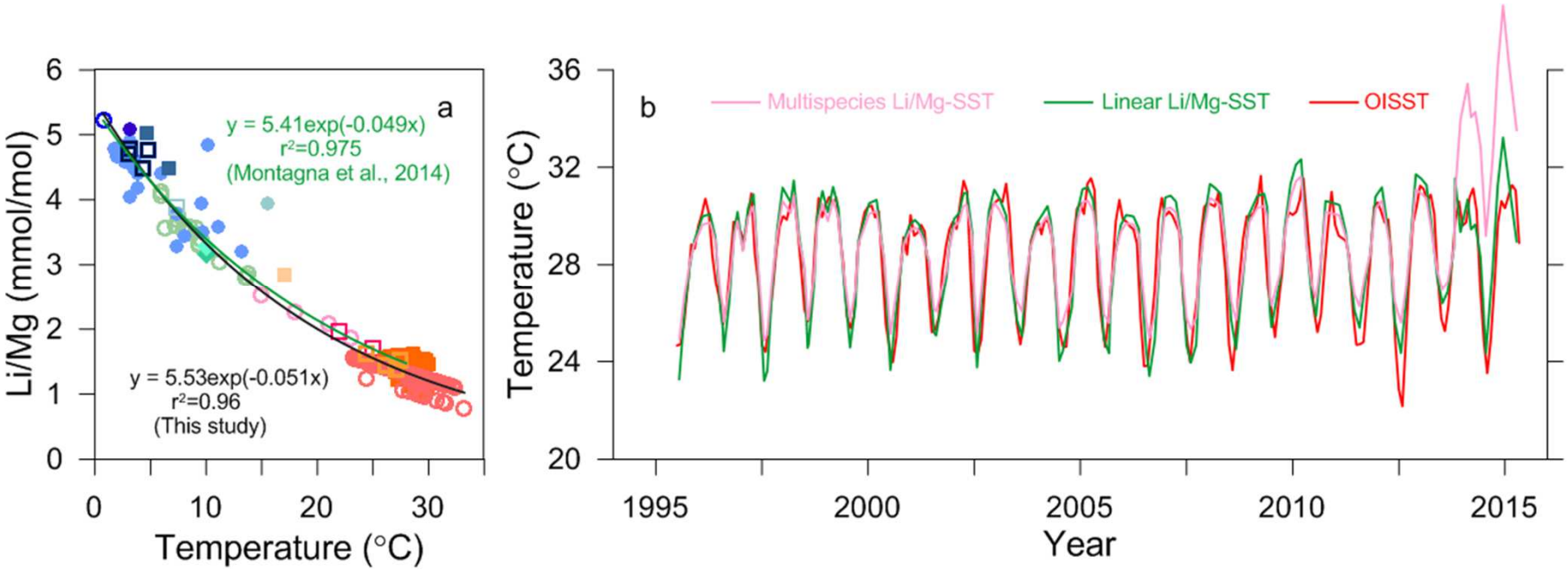
GIGCAS

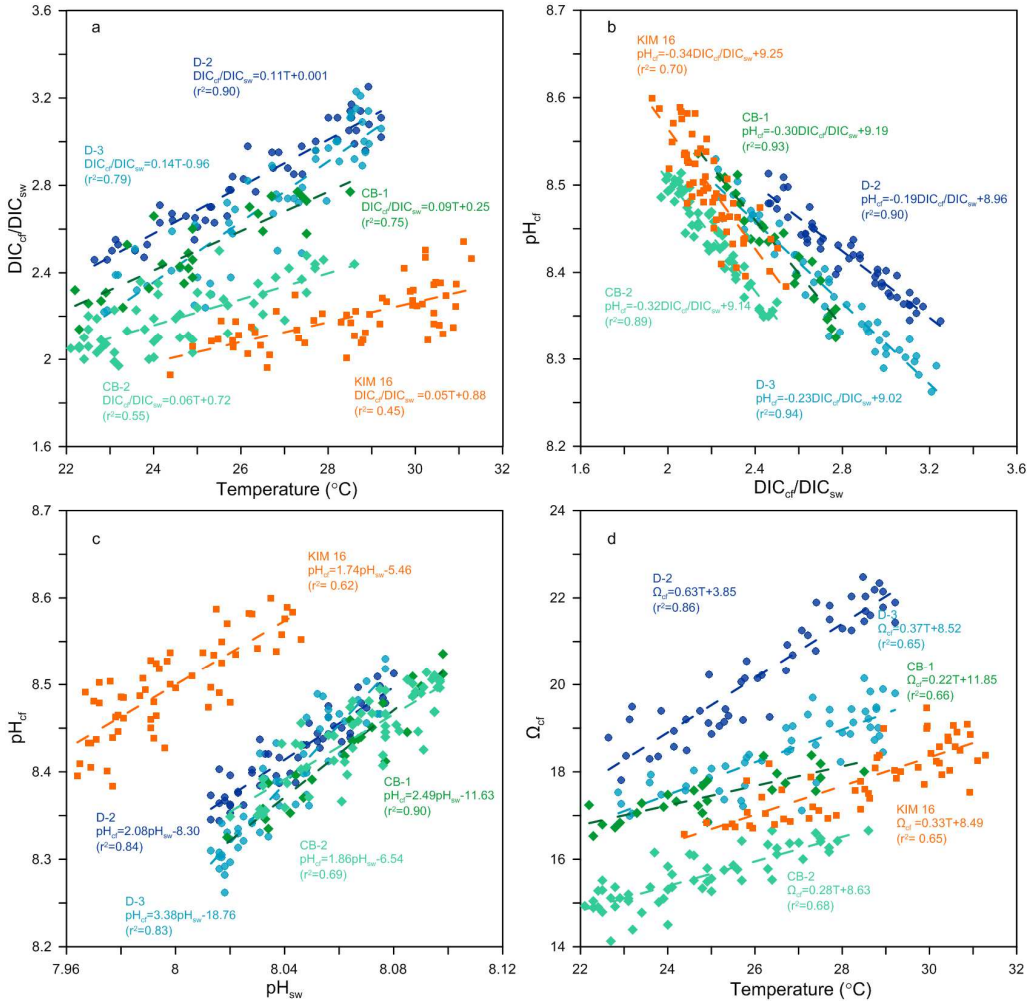
Li/Mg-SST Calibrations

Multispecies Li/Mg-SST relationship



Li/Mg (mmol/mol) = 5.41 exp (-0.049×T (°C)), *Montagna et al., 2014*
Li/Mg (mmol/mol) = 5.53 exp (-0.051×T (°C)), *This study*

Intercolonial comparison



	DIC_{cf}/DIC_{sw}	DIC_{cf} µmol/kg	pH_{cf}	ΔpH	Ω_{cf}
D-2	3.04	5549	8.42	0.38	20
D-3	2.99	5318	8.40	0.36	18
CB-1	2.69	4883	8.43	0.37	17
CB-2	2.33	4322	8.44	0.37	16
KIM16	2.33	4073	8.49	0.49	17

Davies Reef: D-2
D-3
Coral Bay: CB-1
CB-2
Kimberley: KIM16

(McCulloch et al., 2017)