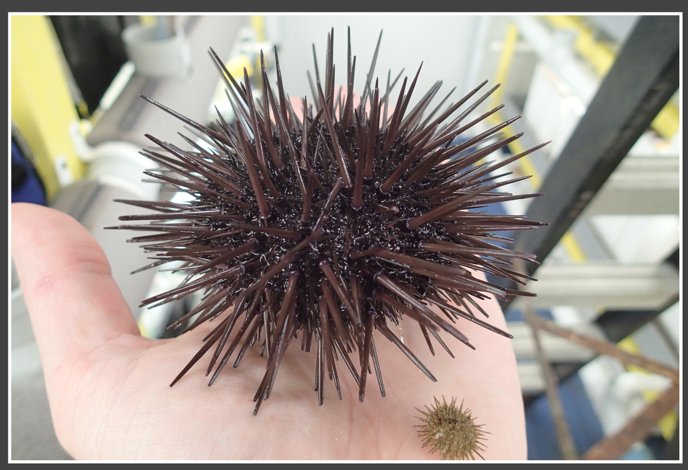

Long-term impacts of ocean **warming** and **acidification** on the sea urchin, *Heliocidaris erythrogramma*

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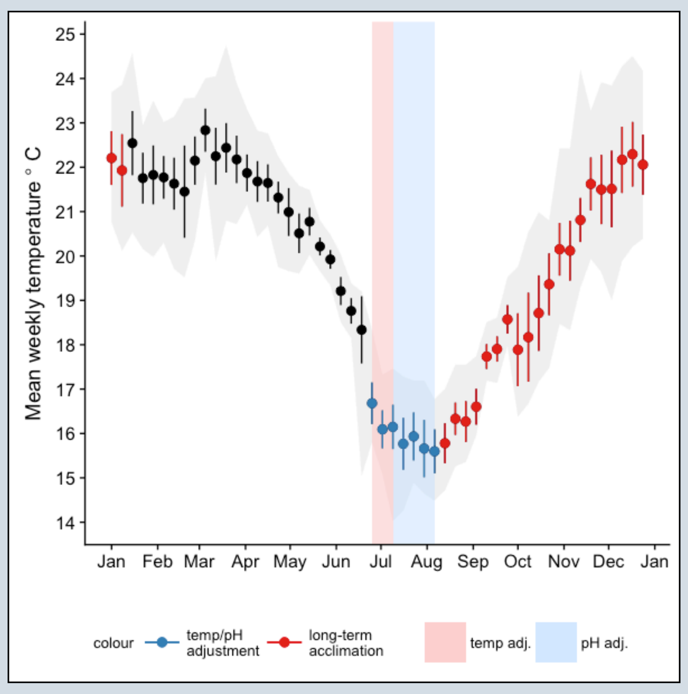
Introduction

The sea urchin, *Heliocidaris erythrogramma*, resides in the ocean warming hotspot of South-East Australia, where temperatures are projected to increase by up to +6 °C in the near future (RCP 8.5, Lenton et al, 2015). Here we present a long-term study on the physiological effects of warming and acidification on the sea urchin over a total of 29 weeks from winter to summer.

Methodology

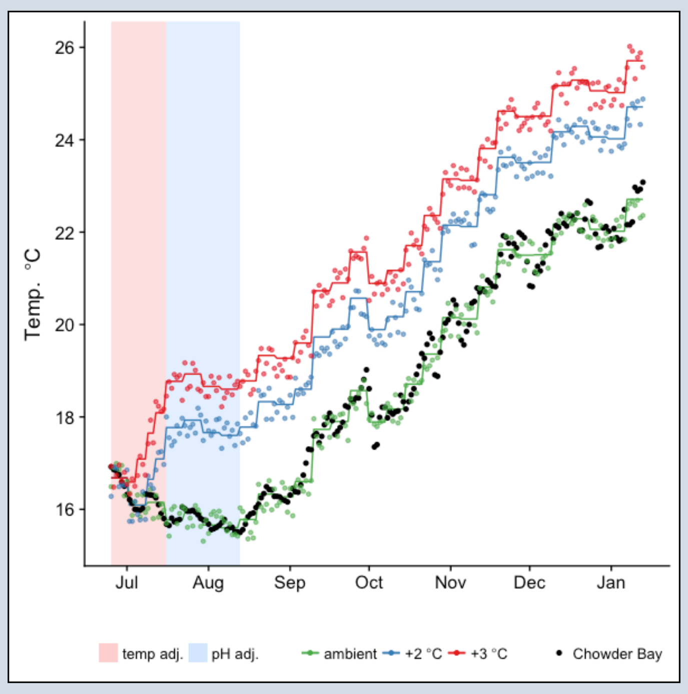
Chowder Bay



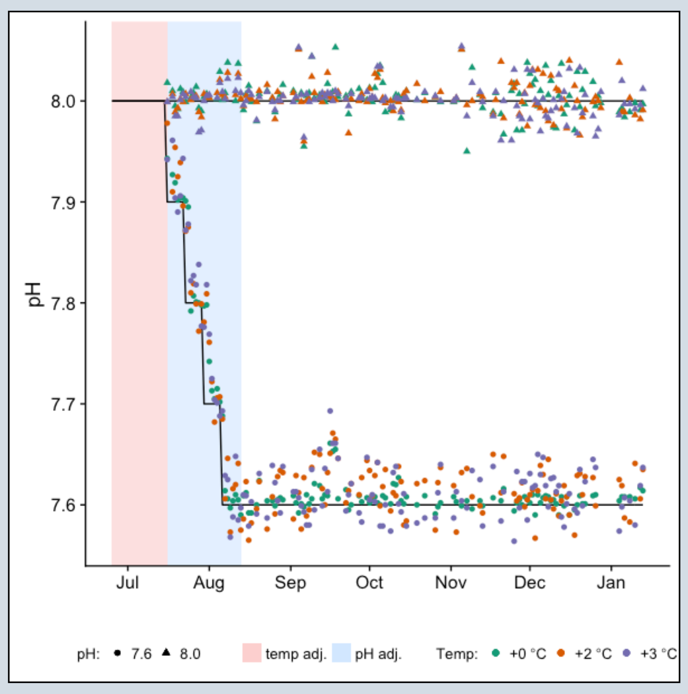
Establishing baseline data. *Heliocidaris erythrogramma* specimens (n = 180) were collected in Sydney Harbour on June, 2014 and maintained at the Sydney Institute of Marine Science. To establish the thermal environment of the sea urchin and to place our experimental data in context, we characterised 6 years of sea surface temperature at one of our urchin collection sites, Chowder Bay.

Left. *Ribbon: max/min temperatures. Error bars: ± s.d.*

Temperature



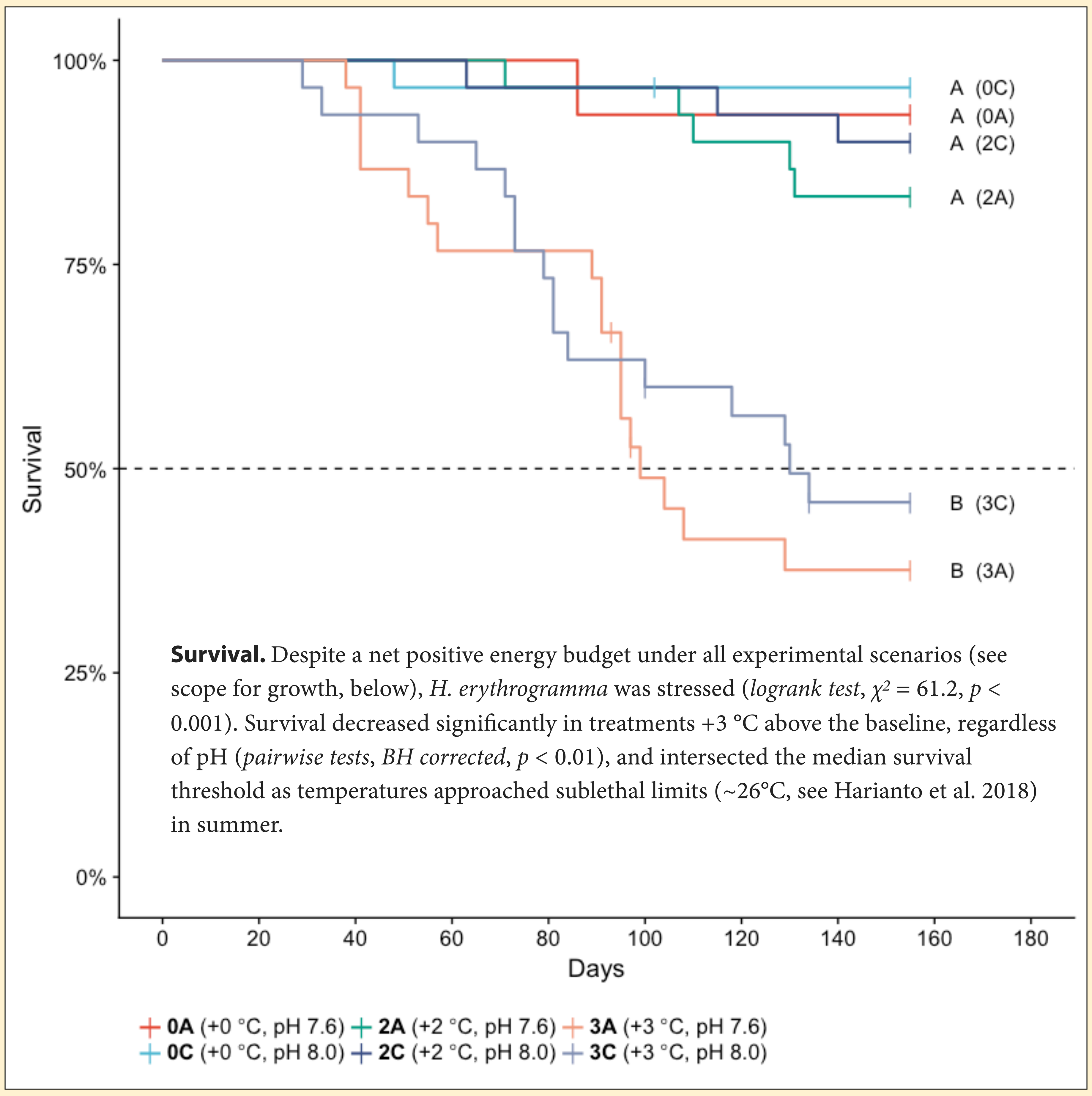
pH



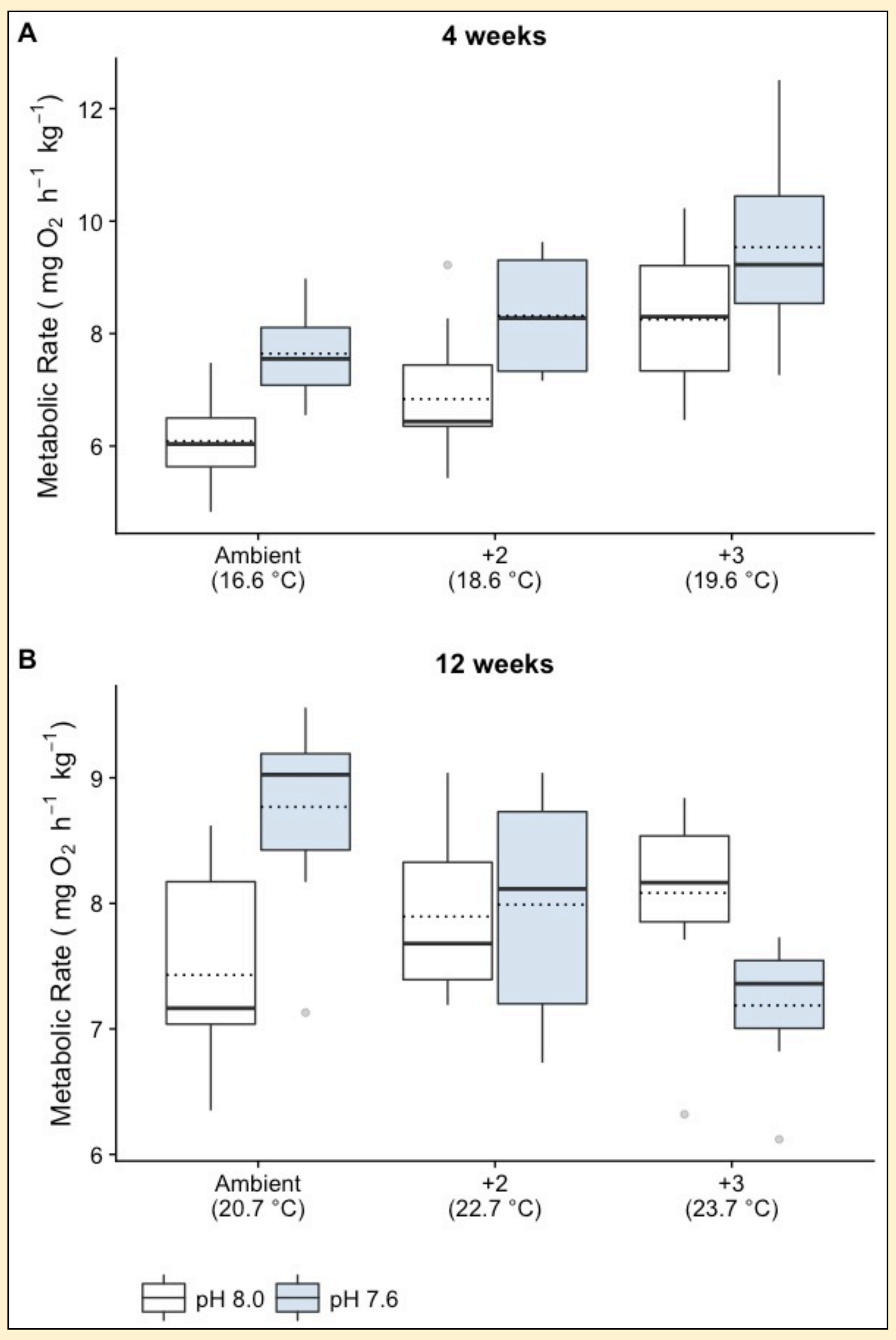
Adjustment (7 weeks): Temperature and pH were adjusted slowly over 7 weeks to minimise physiological shock to altered conditions. There were six treatments of three temperature profiles (ambient: +0 °C, elevated: +2 °C and +3 °C) and two constant pH_T levels (ambient 8.0, low: 7.6). **Acclimation (22 weeks):** temperature levels were regulated *weekly*, based on the baseline data (see above) to mimic the seasonal change expected from winter to summer. pH was kept constant.

Measurements. **Metabolic rate** was measured at 4 and 12 weeks of acclimation, feeding rate and ammonia excretion rate at 12 weeks, and **survival** for 22 weeks. Assimilation efficiency was determined at week 12 for **scope for growth** calculations.

Results



Survival. Despite a net positive energy budget under all experimental scenarios (see scope for growth, below), *H. erythrogramma* was stressed (*logrank test*, χ^2 = 61.2, p < 0.001). Survival decreased significantly in treatments +3 °C above the baseline, regardless of pH (*pairwise tests*, *BH corrected*, p < 0.01), and intersected the median survival threshold as temperatures approached sublethal limits (~26°C, see Harianto et al. 2018) in summer.



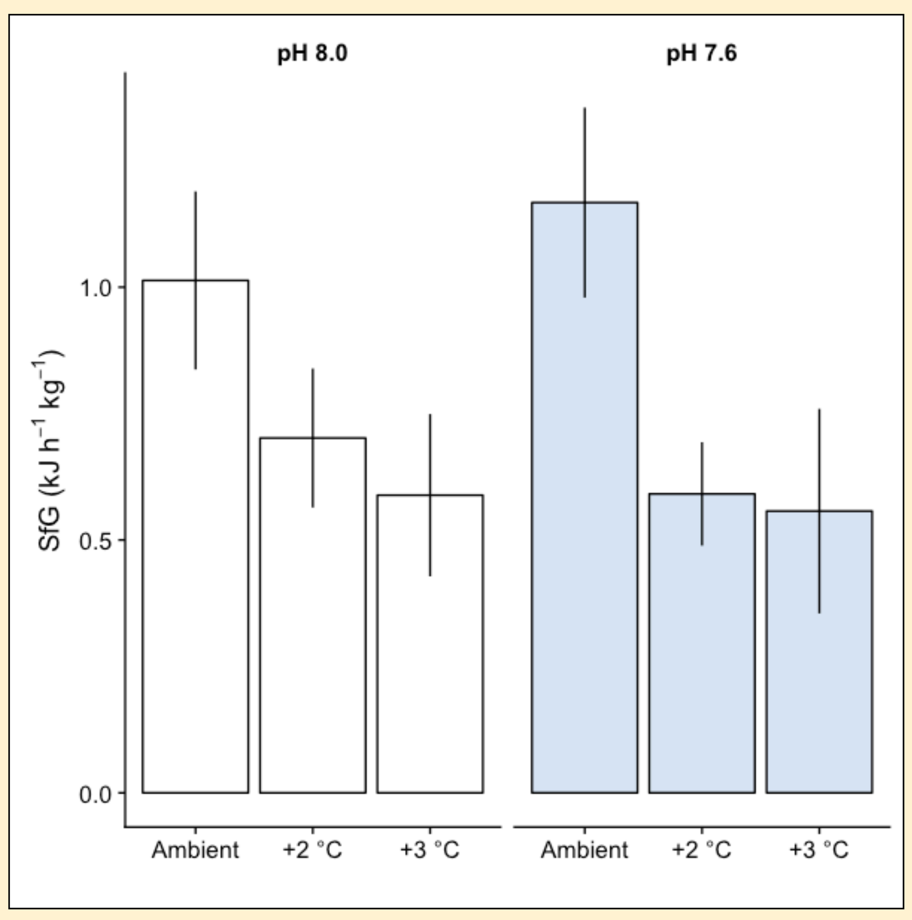
Metabolic rate. There is evidence that the urchins were able to physiologically adjust their metabolic rates, over time, in response to both ocean warming and acidification.

When measured at **4 weeks** of acclimation, metabolic rate increased additively with warming (*GLM*, p < 0.001) or acidification (p < 0.001). Combined effects were ***additive***.

By **12 weeks** of acclimation, temperatures were higher, but ***interaction*** between warming and acidification resulted in decreasing metabolic rate with increased temperature and low pH (*GLM*, p < 0.001).

Scope for Growth. Scope for growth was reduced by 42—45% for urchins that *survived* acclimation to both warming and acidification for 12 weeks. However, energy budget remained net positive under all experimental scenarios, indicating sufficient energy reserves to maintain physiological performance.

Right. *Error bars: ± s.d.*



Conclusions

- ***H. erythrogramma's*** **survival is compromised under long-term +3 °C warming (especially in summer), regardless of pH and positive scope for growth.**
- **Acclimation time influences results — as shown by metabolic rate responses, and highlights the importance of long-term studies.**

References

Lenton A, Mcinnes KL, Grady JGO (2015) Marine projections of warming and ocean acidification in the Australasian Region. Aust Meteorol Oceanogr J 65:S1–S28.

Harianto J, Nguyen HD, Holmes SP, Byrne M (2018) The effect of warming on mortality, metabolic rate, heat-shock protein response and gonad growth in thermally acclimated sea urchins *Heliocidaris erythrogramma*. Mar Biol 165:96.

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