Down in arms: Marine climate stress inhibits growth and calcification of regenerating *Asterias forbesi* (Echinodermata: *Asteroidea*) arms

Hannah Randazzo, 2021

Anthropogenic CO_2 is significantly changing the pCO_2, temperature, and carbonate chemistry of seawater. Recent projections suggest that, within the next century, ocean pCO_2 will increase by approximately 600–700 µatm (ocean acidification) and ocean temperatures will increase by 2.3–3.0 °C (ocean warming).[1] The combined effects of these variables is termed marine climate stress. Particular concern revolves around the capacity for marine climate stress to inhibit the ability of marine organisms to construct carbonate structures.[2] Echinoderms, which have calcium carbonate endoskeletons and the regenerative capacity to reform these endoskeletons in the event of a lost arm, are therefore particularly vulnerable to the effects of ocean change during their regeneration period. Previous studies suggest two opposing hypotheses for the way in which marine climate stress will influence echinoderm calcification, metabolic efficiency, and reproduction: either an additive or synergistic effect.[3,4]

In this study, *Asterias forbesi* were exposed to ocean water of either ambient, high temperature, high pCO_2, or high temperature and high pCO_2 for 60 days, and the regeneration length of the amputated arm was measured weekly. Ocean acidification conditions (pCO_2 ~1180 µatm) had a negative impact on regenerated arm length, and an increase in temperature of +4°C above ambient conditions (Fall, Southern Gulf of Maine) had a positive effect on regenerated arm length, but the additive effects of these two factors resulted in smaller regenerated arms compared to ambient conditions (Figure 1). Sea stars regenerating under high pCO_2 exhibited a lower proportion of calcified mass, which could be the result of a more energetically demanding calcification process associated with marine climate stress (Figure 2). These results indicate that *A. forbesi* calcification is sensitive to increasing pCO_2, and that climate change will have an overall net negative effect on sea star arm regeneration. Such effects could translate into lower predation rates by a key consumer in the temperate rocky intertidal of North America.

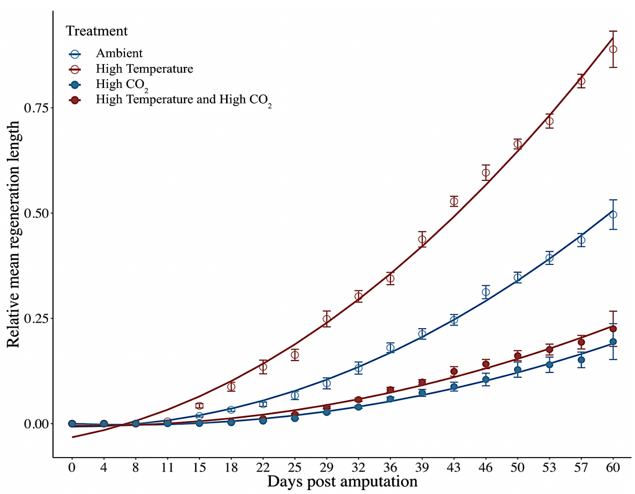

Figure 1. Mean amputated arm regeneration length (mm) normalized for sea star size (average established arm length) as a function of the number of days post amputation for *A. forbesi* (N=24) exposed to marine climate stress conditions. Each point represents average measurements for sea stars in the same treatment. Error bars represent ±SEM. The lines depict the line of best fit (exponential).

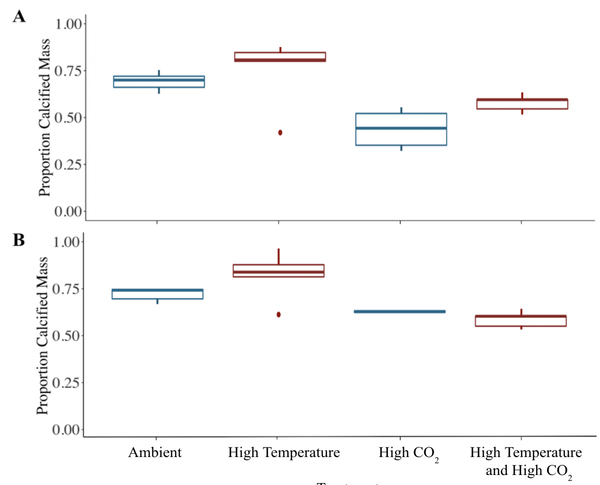

Figure 2. Mean proportion calcified mass (A) in the sampled regenerating arm and (B) in the sampled established arm portions as a function of treatment for *A. forbesi* (N=24) exposed to marine climate stress conditions at 60 days post amputation.

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References

[1] Caldeira and Wickett (2003). *Nature*, 365. [2] Fabry et al. (2008). *ICES J. Mar. Sci.* 414- 432. [3] Bingham et al. (2000). *Can. J. Zool.,* 596-605. [4] Hu et al. (2014). *J. Exp. Biol.*, 2411-2421.