**In ocean acidification life is better in the slow lane**

Unravelling the responses of marine life to ocean acidification is complex.

Ocean acidification describes the many changes to seawater chemistry occurring when carbon dioxide is absorbed into the ocean. Among them is a decline in seawater pH once stable for millions of years but that now occurs simultaneously as the ocean’s take up a third of human-generated CO2 from the atmosphere. As these chemical properties change, particularly pH and the carbonate saturation state, different organisms will react and respond negatively or positively or not at all.

Of most concern is the susceptibility of calcifying organisms that fabricate a calcium carbonate shell or skeleton – because these structures are more likely to dissolve as the carbonate saturation state of seawater declines. In the decade since The Royal Society UK report (2005) alerted scientists to the wide-ranging effects of these changes on marine life, researchers have focussed on the impacts of OA on calcifying organisms, which species might be affected by OA and the physiological mechanisms underlying such responses. Coralline algae, corals, and shellfish are particularly susceptible.

Coralline algae can cover up to 80% of the rock surface on coastlines from the tropics to Antarctica. They are often not recognised as seaweeds, because they appear as ‘pink paint’ on the surface of the rocks. Coralline algae are a group of red seaweeds that fabricate a high-magnesium calcite skeleton; this calcite is most susceptible to dissolution when pH is lowered. Coralline algae provide a range of ecosystem services including substratum stabilisation, habitat creation and primary production, and they provide chemical cues that induce the settlement and metamorphosis of planktonic invertebrate larvae, such as abalone.

In a comprehensive 2013 analysis, Kroeker et al. found that based on laboratory experiments, the extensive coralline algae that hold coral reefs together are considered the most susceptible of all calcifying organisms to OA. The responses of coralline algae to OA will depend on the pH that they encounter. When coralline algae photosynthesize the pH increases as carbon dioxide is consumed by the alga. At night the pH declines as CO2 is released by respiration and calcification.

Seaweeds control pH through their own metabolism but there’s also the velocity of seawater around seaweed to consider.

In slow flows, a microscopic layer of near-stagnant water develops at the seaweed surface. This layer causes higher-pH seawater to be retained at the surface of coralline algae during the day.

In fast flows, seawater at the coralline surface is continuously replenished and so the seaweed has little ability to metabolically control its surface pH. In 2011 we hypothesised that this microscopic layer would protect coralline algae from OA, by providing a higher-pH layer that buffers the algal surface against the reduced pH mainstream seawater. This hypothesis was subsequently proven in an experiment showing that coralline algae growing in slow flows were unaffected by OA whereas those in fast flows exhibited the typical response to OA of reduced growth and calcification. This demonstrated the ability of seaweed to metabolically maintain a higher carbonate saturation state at its surface in slow flows.

These findings for coralline algae suggest that in a future high CO2, low pH ocean, calcifying organisms growing in wave-exposed sites will be more susceptible to OA than those in wave-sheltered sites because their surfaces will be in constant contact with reduced pH seawater.

While we need to extend this test to other vulnerable species, the question arises whether slow circulating flows might provide a refuge.

A strong contender as a refuge habitat is that created by seaweeds and seagrasses which are ‘biogenic engineers’ creating an underwater ‘forest’ habitat on rocky and soft sediment environments. These are the temperate reefs.

Seaweed beds slow the flow of seawater by as much as 95%. Not only are the flows slow, but the seaweeds themselves raise and lower pH on a daily cycle, again due to photosynthesis and respiration. Several studies show that calcifying species growing in seaweed or seagrass beds do better than the same organisms growing outside the beds. Therefore, seaweed beds might create a natural refuge from OA in the future. These seaweed forests are themselves sensitive to environmental change - temperature on a global scale but locally to sedimentation and run-off from the land. They need protecting, not only because of their roles in habitat creation and primary production, but as a potential refuge from OA.

As our understanding of impacts grows, future experiments must take account of stirring and water motion, lest it give a false slant to the fundamental effect on the response of organisms.

Figure: Temperate coralline algae growing in Wellington, New Zealand. Coralline algae can cover up to 80% of the rock surface on coastlines from the tropics to poles. They are often not recognised as seaweeds, because they appear as ‘pink paint’ on the surface of the rocks. Pictured here are encrusting corallines, covering the surface of rocks and living mussels, and ‘upright’ or ‘articulated’ corallines which are branched and form a small canopy (< 10 cm) above the rock surface. Photo: Dr. Christopher E. Cornwall

