ecological transitions within terrestrial plant communities. These types of high-resolution, quantitative assessments of climate factors and the faunal and floral communities within an ecosystem are vital to our understanding of the intricate linkages and feedbacks among these ecological elements. Indeed, knowing how ancient ecosystems responded to changes in the atmospheric CO_2 concentrations will help us more accurately predict responses of modern ecosystems to future increases in greenhouse gases. ❐

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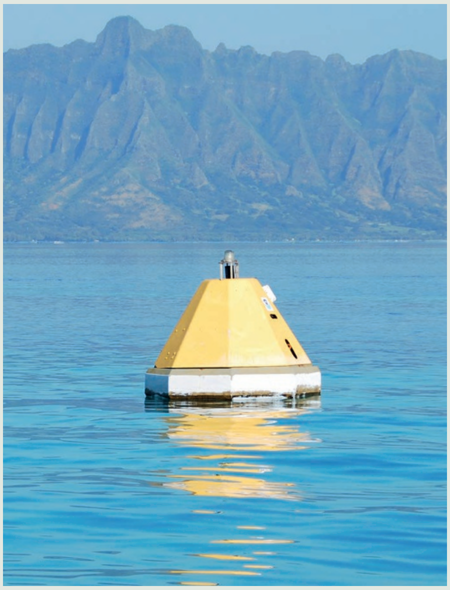
OCEAN ACIDIFICATION

Emergence from pre-industrial conditions

The ocean is a giant buffering system: heat and gases are exchanged at the air–ocean interface, helping to regulate Earth's climate. One-third of all anthropogenic CO_2 released to the atmosphere has been soaked up by the oceans, significantly mitigating the climate impacts of increasing anthropogenic emissions. This service, however, comes at a cost: the increased CO_2 uptake has resulted in shifts in seawater chemistry. Acidity has increased and the saturation state of carbonate minerals — the building blocks for the shells of marine organisms — has decreased. The impacts of this effect, known as ocean acidification, include shell dissolution in marine organisms and alteration of food webs, as well as other potential ecosystem-level changes that are not yet fully understood.

Long-term observations have shown ocean-wide steady increases in acidity and decreases in the saturation state of aragonite — a form of carbonate mineral. Nevertheless, regional patterns of temporal variability may differ, and it is ultimately these local changes that matter most for marine communities. For example, large seasonal and sub-seasonal fluctuations in carbonate chemistry could lead to the adaptation of ecosystems to a larger range of conditions. Therefore, relating present-day variability to the range of pre-industrial conditions provides important context for understanding the response of marine organisms to ocean acidification.

To constrain the sub-seasonal to interannual variability of carbonate chemistry, Adrienne Sutton and colleagues compile a set of high-frequency observations from twelve moorings across three different oceanic regions: open ocean (subtropical and subarctic), coastal ocean and coral reefs. They determine the monthly surface seawater pH and aragonite saturation state at each of these sites since 2010 and compare them with estimates of pre-industrial conditions. In this way they identify regions where current variability goes beyond pre-industrial bounds (*Biogeosciences* **13,** 5065–5083; 2016).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For most of the year, open-ocean and coral-reef sites experience seawater pH levels and aragonite saturation states that are completely outside of the pre-industrial envelope. In contrast, due to large natural variability, present-day observations at coastal sites still overlap with pre-industrial conditions and only fall outside of these during the winter months. Although overlap at these sites can offer coastal ecosystems some respite, biologically important thresholds for the growth and survival of shellfish, for example, may still be exceeded. Indeed, present-day conditions in coastal sites fall below dangerous aragonite saturation states more frequently than in pre-industrial times.

The combination of the following aspects of ocean acidification need to be considered to determine the overall impact on marine life: the gradual increase in acidity, the overlap with the pre-industrial range and the timing and duration of exposure to biologically unfavourable conditions. Pinning down the sub-seasonal, annual and interannual variability of seawater carbonate chemistry will inform local-scale biological-impact studies and improve regional projections of ocean acidification. But ocean acidification is not the only threat to our oceans: increasing temperatures, decreasing oxygen and rising sea levels are some of the changes that are also putting pressure on marine ecosystems. In order to carry out a full vulnerability assessment of marine ecosystems the challenge remains to understand how the complex interaction between the multiple anthropogenic stressors will pan out.

EITHNE TYNAN