Carbon Dioxide, Corals, and Calcification

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This information sheet tells why rising atmospheric carbon dioxide levels are a subtle, but important, long-term threat to reef ecosystems, using the journalistic approach of the "Five Ws and an H" – **Who, What, When, Where, How, and Why.**

Who: (1) The marine plants and symbiotic animals that produce limestone skeletons or deposits by extracting calcium and carbonate from ocean water; and (2) The human race.

What: Reduction of calcification – Skeletal growth or strength reduced, organisms less able to compete for space and withstand predation, lowered production and consolidation of the carbonate minerals that form reef structures, and major changes in oceanic ecosystems.

How: As atmospheric carbon dioxide levels rise, more carbon dioxide dissolves in surface ocean waters, producing carbonic acid. The additional acid changes some of the naturally-occurring carbonate ion into bicarbonate ion, making it less available for biological calcification. This is called "reduction of saturation state."

Why: In about a century, human industrial and economic development combined with population growth have increased carbon dioxide in the atmosphere and surface ocean (largely from burning fossil fuels). Atmospheric levels are now 370 parts per million -- 30% above the upper limit (280 ppm) of values experienced by the Earth over millions of years. The CO2 increase will reach 100% (doubled CO_2) within the present century.

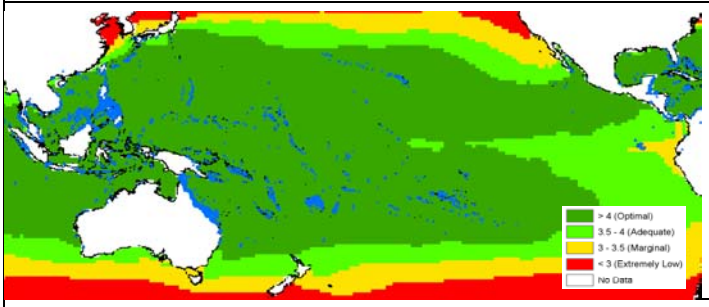
When and Where: The accompanying maps of the Pacific Ocean show the progression from 1870 to 2070 of actual and predicted saturation states for the aragonite form of calcium carbonate. These were calculated at NCAR from geochemical models using actual ocean and atmospheric data, and a conservative IPCC projection of future CO_2 levels.

The Story --- Decreasing carbonate saturation state will gradually but inexorably change the structure and function of reef communities over time, without any of the high profile acute-stress warnings provided by the bleaching response to elevated temperatures. Although all reef calcifiers are likely to be affected, some will be more sensitive than others – similar to what is found with bleaching. The identity, growth, population structures, and local habitats of the reef organisms will become more important for prediction, protection, and management than short-term changes and gross statistics on living coral cover.

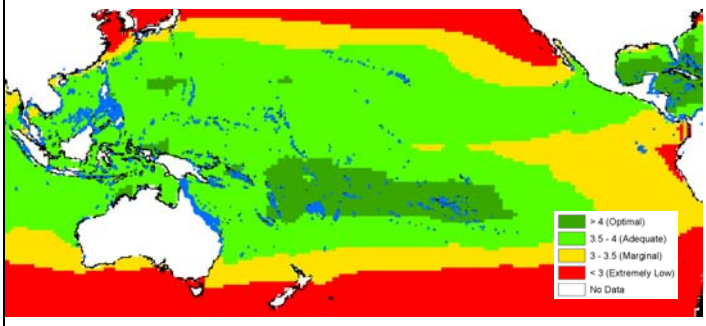
Even in the so-called "marginal" categories portrayed (see maps), corals and reefs are not necessarily doomed; they exist in present-day marginal environments, and calcification rates will be reduced 10-40% below preindustrial levels – not eliminated. However, the present rules for selecting which reefs will be the most robust, suitable for protection, and able to serve as a future environmental and genetic resources will almost certainly change to something very different.

The geographic patterns of change in calcification stress and temperature stress will be very different, and increasingly interactive, so now is the time to learn about the effects of climate-related stresses and the responses of different types of reef communities to different environments and regimes of change. Only with an integrated understanding of how different reef communities respond to multiple stresses over time will we be able to preserve them.

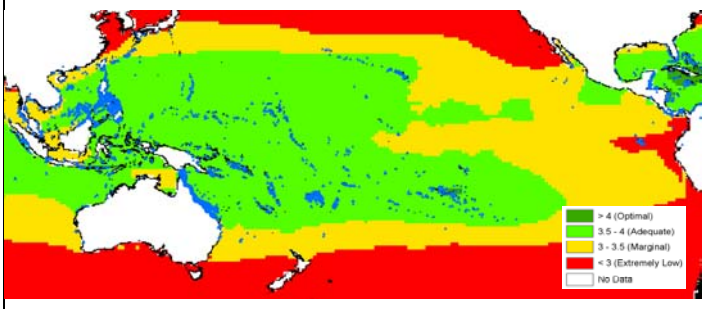
Aragonite Saturation State in the Pacific Ocean, 1870-2070.
Blue dots are reef locations (Reefbase), dark green is optimal for calcification, light green adequate, yellow marginal, and red extremely marginal



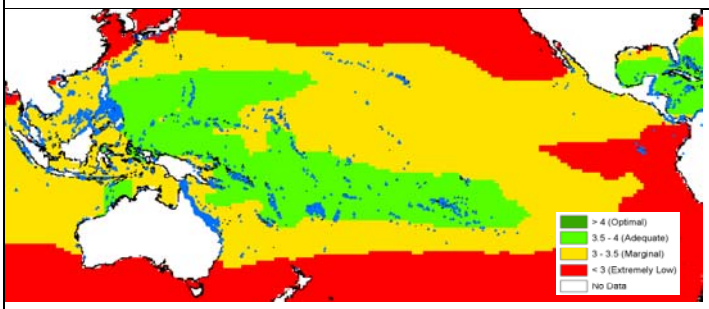
Preindustrial (ca. 1870) conditions – atmospheric CO_2 at 280 ppmv.
Almost all of the world's reefs are in areas where oceanic water is more than 400% supersaturated – and these are close to the lowest values experienced for millions of years. This represents the conditions under which our present reefs developed.



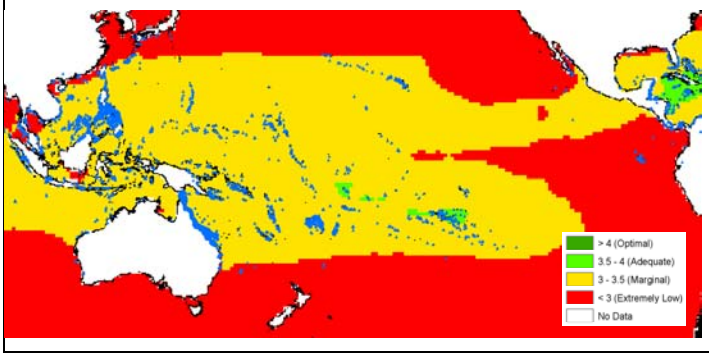
2000-2009 conditions, CO_2 = 375 ppmv.
This very closely approximates present conditions **(~370 ppmv**); most of the changes shown in this figure have already occurred, and experimental studies suggest that long term calcification will be tracking these changes. Responses will depend not only on ocean conditions, but on the organisms present on a given reef.



2020-2029, CO_2 = 415 ppmv
According to projections based on a conservative CO_2 increase scenario, US reefs at high latitudes and in the eastern equatorial region will be entering the 'marginal calcification' category even as they benefit from warmer waters – serving as a training ground and warning system.



2040-2049, CO2 = 465 ppmv
The SE Asian center of biodiversity and the Australian Great Barrier Reef join Hawaii and many of the central Pacific islands in the marginal calcification category—if the lessons have been learned and taught across time and space, managers will understand what to expect, and how best to protect.



2060-2069, CO2 = 517 ppm
Only a few pockets of the 'adequate' category remain, and high latitude reefs are becoming 'extremely marginal' – but tropical ocean temperatures are likely to have stabilized, providing an environment less favorable, but not impossible for reefs -- if their human stewards have preserved them through the intervening changes.