Coral Adaptation in the Face of Climate Change

IN THEIR REVIEW, “CORAL REEFS UNDER RAPID CLIMATE CHANGE and ocean acidification” (14 December 2007, p. 1737), O. Hoegh-Guldberg et al. present future reef scenarios that range from coral-dominated communities to rapidly eroding rubble banks. Notably, none of their scenarios considers the capacity for corals to adapt. The authors dismiss adaptation because “[r]eef-building corals have relatively long generation times and low genetic diversity, making for slow rates of adaptation [relative to rates of change].” We think the possibility of adaptation deserves a second look.

Many features of coral life histories, such as extended life spans, delayed maturation, and colony fission, do result in long generation times (1) [some between 33 and 37 years (2)]. However, other corals, such as many species of Acropora and Pocillopora, mature early, grow rapidly, and suffer whole-colony mortality, as opposed to colony fission, after mechanical disturbances (3) and thermal stress (4). The life histories of these ecologically important and abundant species suggest an underappreciated capacity to adapt rapidly to changing environments.

Repeated bleaching episodes in the same coral assemblages and the increasing scale and frequency of coral bleaching have been cited as evidence that corals have exhausted their genetic capacity to adapt to rising sea surface temperatures (5). However, comparisons of the rates of mortality within populations among bleaching events are not available. Without these data, it is not possible to assess whether the adaptive response has been exhausted. Indeed, the effects of temperature and acidification on even the most basic vital rates in corals, such as growth, mortality, and fecundity, are largely unknown, as are the physiological trade-offs among these traits. Consequently, the sensitivity of population growth to climate-induced changes in vital rates remains almost completely unexplored [but see (6)]. In the absence of long-term demographic studies to detect temporal trends in life history traits, predicting rates of adaptation, and whether they will be exceeded by rates of environmental change, is pure speculation. Indeed, where such data are available for terrestrial organisms they demonstrate that contemporary evolution in response to climate change is possible (7).

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References
Freshwater Forcing: Will History Repeat Itself?  
IN THEIR RESEARCH ARTICLE “REDUCED North Atlantic deep water coeval with the glacial Lake Agassiz freshwater outburst” (4 January, p. 60), H. F. Kleiven et al. present compelling evidence for an abrupt deep-ocean response to the release of freshwater from glacial Lake Agassiz into the northwest Atlantic about 8400 years ago. Such data are particularly important in evaluating the response in ocean models of the Atlantic Meridional Overturning Circulation (MOC) to freshwater forcing. For this event, the freshwater forcing was likely large but short; Clarke et al. (1) estimate that the flood had a freshwater flux of 4 to 9 Sv released in 0.5 years. In this context, we are aware of no possible mechanism that might reproduce such a forcing in response to global warming, and all available model simulations, including those with estimates of maximum Greenland Ice Sheet (GIS) melting rates, indicate that it is very unlikely that the MOC will undergo an abrupt transition during the course of the 21st century (2). Multimodel ensemble averages under Special Report on Emissions Scenario (SRES) A1B suggest a best estimate of 25 to 30% reduction in the overall MOC strength (2). In one example, 14 coupled models simulated a 100-year 0.1-Sv freshwater perturbation to the northern North Atlantic Ocean—17 times the recently estimated melt rates from the GIS—and the MOC weakened by a multimodel mean of 30% after 100 years; none of the models simulated a shutdown (3). Another model simulated greenhouse gas levels that increased to four times preindustrial values and then remained fixed; the resulting GIS displayed a peak melting rate of about 0.1 Sv, with little effect on the MOC (4). One model simulation uses the SRES A1B scenario but adds an additional 0.09-Sv freshwater forcing as an upper-bound estimate of potential GIS melting. In this case, the MOC weakened but subsequently recovered its strength, indicating that GIS melting would not cause abrupt climate change in the 21st century (5). Accordingly, we urge caution in drawing comparisons of the abrupt change 8400 years ago to future scenarios involving, for example, the melting of the GIS and its relevance to human societies.

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Response
WE THANK CLARK ET AL. FOR REITERATING AN important point regarding the relevance of our study (4 January, p. 60) for future global warming scenarios. We agree with Clark and colleagues that the 8400-year deep circulation anomaly we reported, although useful for evaluating the response of ocean models...
to sudden fluxes of freshwater, does not represent the most realistic (one-to-one) analog for possible future changes. Indeed, we found that only one such extreme deep circulation anomaly occurred in the Holocene and that it followed the rapid drainage of an enormous proglacial lake, for which we also know of no foreseeable equivalent in our future. In addition, we pointed out that the ocean circulation prior to the outburst flood was most likely different than it is today—Labrador sea convection and Danish Straight Overflow Water were both thought to be weaker than today (1, 2). Finally, our records demonstrate just how complex the relationship between climate and ocean circulation was during the rest of the Holocene.

We demonstrated that the ocean sensitively responded to the extreme freshwater forcing event ~8400 years ago. Our results agree with modeling studies applying similarly large freshwater fluxes, confirming that the deep ocean can change just as quickly as models predict (3). In the most general sense, this supports the idea that the estimated 25 to 30% reduction (4) in Meridional Overturning Circulation (MOC) referred to by Clark et al. is plausible on century time scales.

Our approach for understanding the extreme and distinctly different scenario ~8400 years ago may also be useful in determining the sensitivity and thresholds of ocean circulation for the more modest but sustained freshwater forcing expected in our future. Further work will be necessary to validate the scale and rate of MOC changes estimated by models in these intermediary states. A natural next step would be to provide a detailed characterization of deep-water properties and circulation at times in our past that contain elements more in common with our future. One obvious candidate is the previous interglacial period (Marine Isotope Stage 5e), which was warmer than the present (5), had a smaller Greenland Ice Sheet, and may have experienced a sea-level rise at a similar rate to that projected (6).

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