ECOLOGY

Kelp in postglacial time

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In a multifaceted exercise in palaeoecology, Michael Graham and colleagues have taken the subject underwater. Their study is an investigation of how the distribution and productivity of giant kelp have changed since the end of the Last Glacial Maximum, about 20,000 years ago, in one of its present-day strongholds, the Southern California Bight (M. H. Graham *et al.* *Proc. R. Soc. B* doi:10.1098/rspb.2009.1664; 2009).

The significance of giant kelp (*Macrocystis pyrifera*; pictured) is that it is a foundation species — a dominant primary producer — that creates vast submarine forests in coastal areas of temperate regions. These kelp forests constitute ecosystems on which a multitude of other species depend.

Delving into the past of marine algae such as kelp poses particular challenges. Unlike the terrestrial flora, for example, there is no pollen record to track a shift in species abundance. Graham *et al.* had to find less direct approaches.

The authors worked on the assumption that the environmental needs of kelp have not varied over the past 20 millennia. They created 'niche-based' reconstructions through time of factors that primarily included the availability of a rocky sea floor in adequate light conditions, at depths of up to 25 metres. These reconstructions were complemented by palaeo-oceanographic records that allowed estimates of nutrient availability, and so of kelp productivity.

The result is a millennial-scale account of the dynamics of southern Californian kelp forests. The patterns are swiftly changing and complex. But the broad picture is of an apparent increase in biomass of three times or so from glacial-maximum levels until about 7,500 years ago, followed by a rapid fall of as much as 70% to today's levels.

An archaeological twist comes from a link between the food resources furnished by kelp forests and early human settlements. There is documentation of this for California, and Graham *et al.* suggest that past human migrations might also have had a kelp connection.

Tim Lincoln

during the Eocene–Oligocene climate transition that began about 34 million years ago. This was a time of dramatic climate perturbation, which saw the formation of the still-extant Antarctic ice cap, and which has been attributed to changes in the global carbon cycle[5].

Boron has a physicochemical property that is particularly appropriate for reconstructing historical levels of atmospheric CO_2. The relative abundance of its two stable isotopes ($^{11}B/^{10}B$, designated $\delta^{11}B$) in the shells of foraminifera is correlated with the pH of the uppermost ocean layers in which these organisms lived[6,7]. Because atmospheric CO_2 is in chemical equilibrium with the pH of surface sea water, it is possible to infer past CO_2 concentrations from boron isotopes in carbonate sediments[8]. By comparing their boron-isotope results with published oxygen data[9] from samples of the same age, Pearson *et al.*[1] reach two intriguing conclusions.

First, they conclude that the slow temperature decline recorded by oxygen isotopes was concomitant with a decline of atmospheric CO_2 from about 1,100 p.p.m.v. to a threshold concentration of about 750 p.p.m.v., at which the main phase of Antarctic ice-cap growth was initiated. This finding confirms model predictions[5] that — contrary to what might be expected — the initiation and the rapid expansion of the Antarctic ice sheet occurred about 33.5 million years ago at levels of atmospheric CO_2 that were more than twice the present-day value. Pearson *et al.* propose that the Antarctic glaciation was preconditioned by the global cooling associated with the decline of atmospheric CO_2. But the glaciation really started only when Earth's orbital parameters, which change periodically, favoured the process.

The authors' second conclusion is that, although the newly formed ice cap may have shrunk somewhat, it largely survived a subsequent and rapid recovery of atmospheric CO_2 back to levels of 1,000 p.p.m.v. or more. Such a rise in CO_2 after the main phase of ice-sheet growth is predicted by climate models[10]. But the boron isotopes indicate that it occurred within the following 50,000 years, which is faster than the model prediction. This disparity highlights a need for more refinement in modelling the carbon cycle and understanding its relationship with global climate.

The inferences drawn by Pearson *et al.*[1] about relative variations in boron isotopes — and, hence, in the pH of 'palaeo-seawater' — are solid. But caveats must be mentioned about the extrapolation of boron-isotope data in determining the corresponding atmospheric CO_2 concentration[11]. Reliable absolute values of seawater pH can be deduced from boron isotopes in shells of ancient marine organisms only once the $\delta^{11}B$ value of sea water itself is known, which is not readily achieved for the situation 33.5 million years ago. Even when the pH of palaeo-seawater is correctly estimated, more information on seawater chemistry (in particular with respect to the dissolved carbonate species) is still required to deduce the corresponding atmospheric CO_2 at equilibrium. Possible errors in doing so may arise from the method itself — which involves using fluid inclusions in salt deposits to reconstruct open-ocean chemistry[12] — or from the determination of the ancient seawater saturation state with respect to carbonate[13]. The boron data might tell a slightly different story if the model used for palaeo-seawater chemistry turns out to have flaws.

Nonetheless, as they stand, the results validate climate models at CO_2 concentrations not observable in the instrumental and ice-core archives. The unequivocal advance made by Pearson *et al.*[1] is to demonstrate that marine organisms that existed when the Antarctic ice cap formed show much lower $\delta^{11}B$ values than do such organisms today — probably indicating lower seawater pH and higher CO_2 levels than today — and that they record sharp variations in CO_2 associated with the main phase of ice-cap growth. Their high-quality data will further invigorate study of the coupling between global temperature, ice volume and atmospheric CO_2 in ancient times — and that is no mean achievement. ■

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