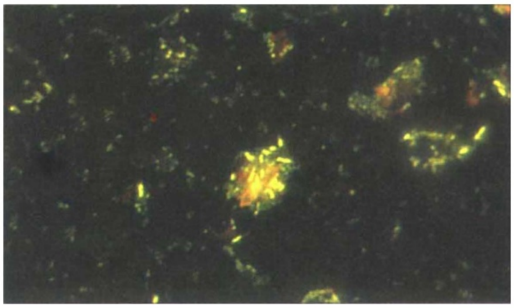

Small world — a preparation of planktonic lake bacteria, stained with a green nucleic-acid stain and photographed with epifluorescence at ×2,360, showing bacterial colonies and single organisms. (Photograph courtesy of P. del Giorgio.)

and phytoplankton in waters ranging from lakes to the open ocean. They begin by pointing out that there is a significant correlation between bacterial abundance (which is even easier to measure than production) and bacterial respiration in a wide variety of waters; this is an expected observation that lends credibility to their unexpected conclusion. The heart of the paper, though, is discussion of the relationship between bacterial respiration and primary production. It is not surprising that the authors observe a correlation between these two processes. What is surprising is that when primary production falls below roughly 100 $\mu g\ C\ l^{-1}\ d^{-1}$, bacteria outeat what phytoplankton produce.

Before explaining how any heterotrophic process could exceed primary production, del Giorgio *et al.* defend their conclusion by comparing their bacterial respiration estimates with available data on bacterial production. To do so, they needed to calculate bacterial growth efficiencies, which are a measure of how much organic carbon taken up by bacteria is either transformed into bacterial carbon or respired as CO_2. The growth efficiencies they calculated range from 10 to 30%, and are lower than that commonly assumed (50%) in ecological models but similar to those directly measured in studies published last year[3,4]. These figures support the estimates of high rates of bacterial respiration.

The authors go on to hypothesize that growth efficiencies increase with rates of primary production, a view that has many implications for thinking about carbon cycling in lakes and oceans. Although many will argue with del Giorgio *et al.* about the high estimates for respiration, few will find fault with their calculations of low growth efficiencies and the proposal that these efficiencies vary systematically.

The dilemma is then to explain how bacterial respiration could ever be greater than primary production. For lakes, runoff carrying organic material from land (what ecologists call allochthonous carbon) could fuel bacterial respiration independently of phytoplankton production, and indeed del Giorgio *et al.* point out that some lakes are supersaturated with CO_2. A similar mechanism is at least conceivable, although debatable, for estuaries and coastal oceans.

But the authors run into real problems with the open ocean, where DOM comes almost entirely from marine sources[5]. They say that highly productive oceanic regions could export DOM to less productive areas and the exported DOM could then fuel high bacterial respiration in waters with low primary production. Although there is some evidence for DOM export[6], what seems more plausible is that, as del Giorgio *et al.* suggest, bacterial respiration and primary production are simply not in synch over time.

A specific example may explain this best. During a phytoplankton bloom in the North Atlantic in 1989, primary production was low but bacterial activity remained high on cloudy days[7]. For those days, bacterial respiration exceeded primary production, according to calculations based on the growth efficiencies provided by del Giorgio *et al.* and measured rates of production. The cloudy days, however, were balanced out by sunny ones when primary production was much higher than bacterial respiration. A few days of net heterotrophy may seem more plausible when we remember that phytoplankton release little DOM directly[8]. Grazing and other processes distant in time from phytoplankton are the most likely sources of DOM to support high rates of bacterial respiration when primary production is low.

The new work[1] will be an inviting target for sceptics, as indeed would any study that spans the gamut from nutrient-rich lakes to nutrient-poor open oceans. Even if the imbalance between heterotrophy and autotrophy is eventually righted, bacterial respiration is likely to loom large in future models of carbon cycles. It is becoming clearer and clearer that the Earth remains firmly in the Age of Bacteria — and it will be much easier to revisit the lakes and oceans of del Giorgio *et al.* than to test whether life really did once exist on Mars. □

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DAEDALUS

God plays dice

The relativistic and quantum views of the Universe are still irreconcilable. Daedalus now points out the theological implications. If the relativistic view is correct, the Universe is an *n*-dimensional manifold with time as one dimension. It is a completely defined structure, and everything in it is already determined, future as well as past. God may have declared it good, but there is nothing He or we can do about it now.

The quantum view is quite different. The Universe is steadily emerging from innumerable quantum uncertainties, 'dice thrown by God', as Einstein saw it. Newton himself felt that God must intervene now and then in His creation to keep it on track; and the uncertainty principle provides the ideal mechanism. By tweaking key parameters by less than their Heisenberg uncertainty, He could affect distant outcomes without breaking any physical law. The outcomes, however, might be inconveniently distant. Suppose, for example, that He wished to annihilate the dinosaurs by meteoric collision. He'd have to start the strategy some 100 million years ahead, at which time the required adjustments to the position or momentum of the best available asteroid would be below the Heisenberg limit. But at that time He wouldn't know what sort of dinosaurs would be around — the uncertainty of evolution must multiply up at a much faster rate. If He left the decision till the dinosaurs were already defined, it would be too late to do more than merely shift the aim-point of the asteroid by a kilometre or so.

In other areas, chaos theory allows God to move more rapidly. He could control the weather perhaps a month or two ahead, by tweaking sub-Heisenberg atmospheric fluctuations. And on small highly chaotic systems like the random-noise generators and tumbling balls used to select lottery winners, He could act almost instantly.

So DREADCO statisticians are studying the records of the British national lottery. It is probably naive to see if the good are significantly over-represented among the winners. God must take a long view, and His social purposes may lie generations ahead. But Daedalus recalls Galton's statistical study of the power of prayer. On average, all lottery players must wish to win equally fervently, no matter how much they have staked. If these wishes affect their chance of winning, a £1,000 punter will not be quite 1,000 times as likely to win as a £1 one. The ratio will be (1,000+*x*):(1+*x*), where *x* is the power of wishing. Daedalus hopes to deduce *x* from the statistics, and thus discover the influence of human desires on the Divine purpose.

David Jones

