going heritable and cumulative changes in the expression of genes involved in DNA metabolism. Acute doses of UV-B (as well as ionizing radiation) have been shown to activate transposable elements[4], and the damage done to DNA by such elements might also be involved in the induction of repair genes, creating a sort of damage–repair chain reaction. It is possible that some sort of signal regarding genomic stress is passed from one generation to the next. This may be an example of what Barbara McClintock described as "the response of the genome to shock"[5] after observing the activation of transposable elements in maize after the induction of a chromosome break. Whether the environmentally induced genomic instability seen here represents the same or a related phenomenon remains to be seen.

This study presents intriguing data suggesting that depletion of the ozone layer may have a measurable effect on the mutation rate of at least some plants. But further work to determine the mutation rate and the spectrum of mutations caused by UV-B exposure are required before we can fully assess the significance of these observations. ■

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Aquatic ecology

Phosphorus, the staff of life

David M. Karl

All organisms require nutrients in trace or comparatively much larger (macro) amounts. Phosphorus is one such macronutrient, accounting for about 2–4% of the dry weight of most cells. Life is truly built around phosphorus[1]. Yet despite its well-accepted ecological role, quantitative studies of the nutrient's dynamics are limited by the analytical methods available. In many aquatic environments, phosphate — PO_4^{3-}, the preferred substrate for microbial growth — is 'undetectable'. That is, it is technically below the limit of approximately 30 nanomolar (10^{-9} molar) of standard methods.

On page 54 of this issue, Hudson *et al.*[2] reveal just how small the ambient pools of phosphate can be. They have assessed phosphate and total phosphorus (both dissolved and particulate forms) in a diverse set of 56 North American lakes of different nutrient status. They find that phosphate levels are two to three orders of magnitude lower than previously thought — the range was from 27 to 885 picomolar (10^{-12}), with a mean of 174 pM. Using an indirect steady-state radio-bioassay, the authors estimated ambient phosphate by direct measurements of the rates of uptake by microorganisms and recycling back into the ecosystem. Application of the commonly used but imperfect 'soluble reactive P' method and the improved 'Rigler bioassay' to these same habitats yielded phosphate estimates that were 100–1,000 times higher.

Incredibly, even at ambient phosphate concentrations of 50 pM or less, microbiological uptake in the lake ecosystems was rapid and efficient. This indicates that phosphorus was the limiting nutrient, its availability being the main brake on primary productivity. A counterintuitive result was the significant positive correlation between phosphate and total phosphorus concentrations, implying that low standing stocks of microbes are most efficient at removing phosphate from the water. However, the ambient pool is ultimately controlled by a complex balance of factors — phosphate delivery to and export from the ecosystem; microbial and non-biological uptake and release; and local mineralization of organic phosphorus. One unstated implication of the low phosphate levels and rapid (< 10 min) turnover times in these natural aquatic habitats is that phosphorus flux, not quantity, is probably the more ecologically relevant parameter.

Among the other implications is the

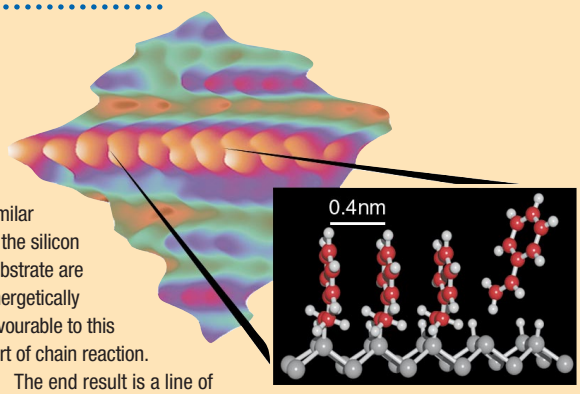
Molecular nanostructures

Growth in the fast lane

Controlling the formation of nanostructures at the molecular scale is a great technological challenge in the design of electronic circuits and devices. Molecular manipulation is a tricky business and, although there is scope for greater miniaturization of electronic components, future developments will require an even closer integration between chemistry, biology, physics and engineering. The most promising approaches so far — using scanning tunnelling microscopes (STM) or self-assembly processes — are either too slow or do not allow accurate monitoring of the growth of these structures.

Elsewhere in this issue (*Nature* **406,** 48–51; 2000), Robert Wolkow and colleagues describe how they have created one-dimensional organic structures on a silicon surface, by combining STM and self-directed growth techniques. The picture on the left shows an STM image of a straight line of styrene molecules (C_8H_8; red) attached to a silicon surface. This is an ideal substrate for the assembly of straight 'wires' because it is anisotropic; that is, the growth process proceeds in one direction, which depends on the crystallographic orientation of the surface.

How are these molecular wires produced? The first step is to expose a clean surface of silicon to atomic hydrogen in an ultra-high vacuum to obtain a surface terminated by hydrogen atoms. A hydrogen atom is then removed from the surface with the tip of an STM to create a single silicon dangling bond, which will then spontaneously react with any available styrene to form a silicon–carbon bond. To compensate for this newly reactive carbon species, it is likely that a hydrogen atom is removed from a neighbouring surface site, leading to a chain reaction. Theoretical calculations have shown that anisotropic surfaces similar to the silicon substrate are energetically favourable to this sort of chain reaction.



The end result is a line of styrene molecules bonded to the surface. The longest chains created were 13 nm long. The phenyl rings of the styrene molecules were separated by 0.4 nm (right image), which corresponds to the intermolecular distance between two hydrogen atoms on this surface. Although it is not possible to tell whether the rings are actually parallel, some degree of intermolecular coupling between adjacent rings would be necessary for these chains to function as molecular wires.

As the authors point out, the process could be applied to other organic molecules, such as alkenes and alkynes, which may be used to design conducting wires. Many factors need to be explored to help unravel the exact growth mechanism, but this approach is already sufficiently under control for one to imagine the rapid formation and connection of many nanostructures in parallel.

Vincent Dusastre

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apparent ability of planktonic microbes to take up phosphate at levels of less than one part per trillion, which appears to be comparable to the assimilation efficiency of many trace elements. At the lowest concentrations reported (under 50 pM), uptake could be limited by diffusion, especially at the inferred growth rates in these habitats. This should select for very small organisms with large surface-to-volume ratios. Ironically, on a mass-for-mass basis, small bacterial cells have higher requirements for phosphorus than do larger organisms in the phytoplankton. So the bacteria may be net sinks for phosphorus, rather than efficient remineralizers of the element as is often assumed.

If this is true, then the supply of phosphorus to the weaker photosynthetic competitors must come from other sources, such as dissolved organic phosphorus or direct ingestion of other organisms, or from vertical migration or other adaptations that enable them to tap into different sources of the nutrient. It is equally likely that the competitive microorganisms in these habitats do not exist in our pure culture collections. So we can expect there to be hitherto unknown transport systems or other physiological adaptations for phosphate uptake.

In recent years there has been a renewed debate over which nutrients are the proximate and ultimate rate-limiting factors on primary production in aquatic environments[3,4]. In both freshwater and marine habitats, the phosphorus and nitrogen cycles are inextricably linked by the stoichiometry of organic-matter production and remineralization. Under certain conditions, however, microorganisms that can fix nitrogen gas decouple this nutrient interdependency and drive the ecosystem to phosphorus-limitation.

For instance, I have hypothesized that within the past two decades an oceanic area, the North Pacific subtropical gyre, has shifted from a nitrogen-controlled to a phosphorus-controlled habitat as a result of climate-driven selection for the nitrogen-fixing cyanobacterium *Trichodesmium*[5,6]. From Hudson and colleagues' regression plot of soluble phosphate against total phosphorus, one would predict a further reduction in North Pacific phosphate concentrations from the present 20–50 nM to around 100 pM, or less.

Elsewhere, measurements using a new high-sensitivity, high-specificity assay[7] in the Sargasso Sea in the North Atlantic, another region of increased nitrogen fixation, indicate sub-nanomolar phosphate concentrations (ref. 8, and J. Wu and E. A. Boyle, unpublished results). In these open-ocean habitats, phosphate concentrations may ultimately be controlled by the atmospheric deposition of dust, which supplies the iron needed to sustain maximal activity of the nitrogenase enzyme responsible for nitrogen fixation[9].

Finally, 'luxury' uptake and internal storage of phosphorus is a well-documented metabolic trait in the microbial world. If freshwater microorganisms can efficiently remove phosphate at ambient levels of at least 27 pM, and still sustain optimal growth, then any concentration above that level might be considered excess. From this it would seem that most aquatic habitats, including both freshwater and marine ecosystems, should have only trace levels of phosphate and should be populated with small microbial cells that are enriched in phosphorus relative to carbon or nitrogen.

However, this is not generally observed; indeed, phosphorus-controlled populations often have lower P:C and P:N ratios than expected. An alternative mechanism to achieve the low phosphate levels in the lakes examined by Hudson *et al.*[2] is adsorption onto clay minerals, iron-rich particles or colloidal organic materials. Although they are much less interesting from a physiological perspective, non-biological as well as biological mechanisms of phosphate removal are ecologically relevant.

All in all, we are left with a sobering thought — that the results of Hudson *et al.* mean that a large literature on phosphate concentrations in aquatic ecosystems, and also models of nutrient dynamics, may be in jeopardy. The authors do not present data for other macronutrients or trace nutrients. But it seems likely that, at least in the lakes that they studied, phosphorus is the limiting nutrient and so the staff of life — the most essential of nutrients. If the results are confirmed, this study will stand as a pathfinding contribution in aquatic ecology. ■

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Population biology

Parasites take control

Richard D. Gregory and Peter J. Hudson

Parasites may make up half of the animal species on Earth[1], yet their impact on the populations of their unwilling hosts is largely unknown[2]. Theory has defined the conditions under which parasites might stabilize and regulate host numbers[3]. But although it seems that they can cause cyclic fluctuations in host numbers[4], there is no sound evidence of stable regulation by parasites of natural populations because the experiments required are very difficult.

An alternative method is to look at the relationship between an invading parasite and its host, and show that the pathogen not only reduces the size of the population, but also keeps it low. As they report in *Proceedings of the National Academy of Sciences*[5], Hochachka and Dhondt have used this approach to demonstrate how parasites can indeed control host numbers.

The authors followed the invasion by a bacterial parasite of a songbird population in eastern North America. The bird — the house finch *Carpodacus mexicanus* — is a small (20 g) native of western North America that was introduced onto Long Island, New York, in 1940. At first the population failed to thrive. But in the 1960s the finch's numbers and range in eastern North America started increasing dramatically, and in 1995 the eastern and western populations met; at the time house finches numbered several millions and occupied most of eastern North America.



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Figure 1 **A male house finch of the species studied by Hochachka and Dhondt[5], with the debilitating symptoms of mycoplasmal conjunctivitis. As the disease develops, finches lose weight, become increasingly weak and either die of starvation or are taken by predators.**

The parasite concerned, *Mycoplasma gallisepticum*, causes conjuctivitis in the eyes of infected birds (Fig. 1). It was known to infect poultry, but had not been previously reported in wild birds. The first signs of disease came in 1994, when birdwatchers reported cases of conjunctivitis in the eastern population of finches at garden feeders in Washington DC. The bacterium turned out to be a distinct strain from that found in poultry[6] and experimental infections have confirmed its

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