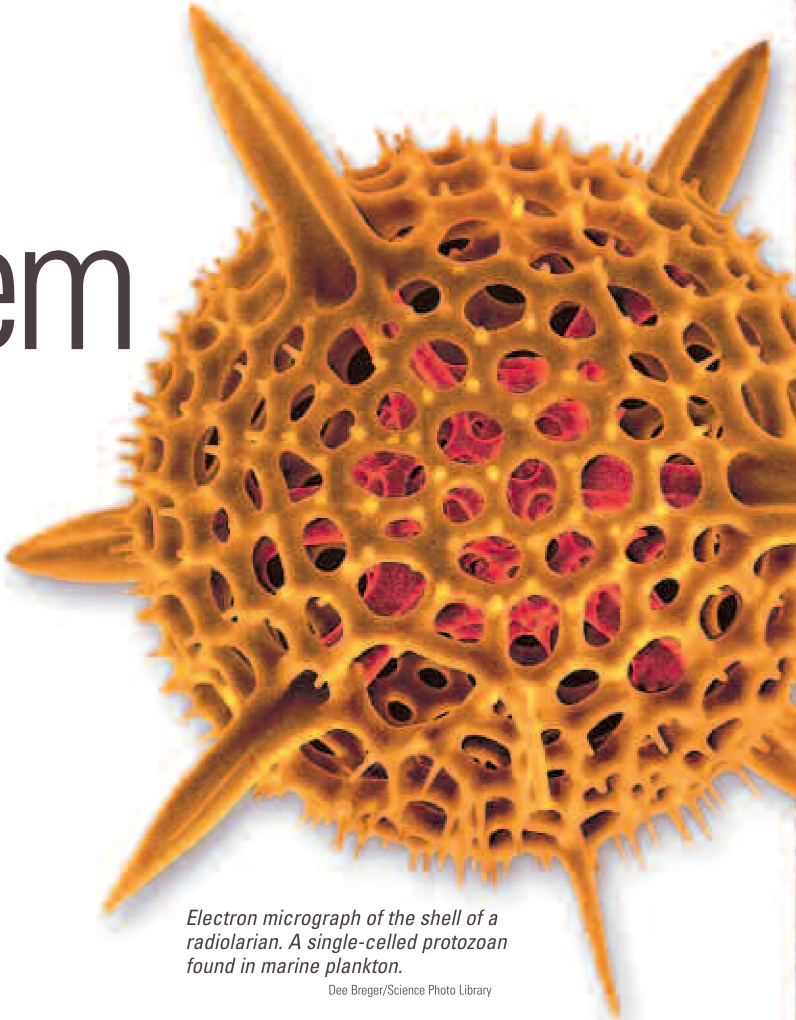
Can't live without them

Microbial biodiversity is one of our greatest natural resources. So say Phil Williamson, Grant Burgess and Ian Joint at the end of a major research programme on the invisible life in marine and freshwater environments.



Electron micrograph of the shell of a radiolarian. A single-celled protozoan found in marine plankton.
Dee Breger/Science Photo Library

Would you welcome an indestructible and indiscriminate super-disinfectant that wiped out all organisms that are too small to see? Bacteria, viruses and other microbes – what would life be like without them? For the first week it would be the best news ever. Hospitals would empty, and economic activity would soar. Problems in breweries and bakeries, and collapsing sales of fridge-freezers, would only merit a few small paragraphs on page eight of the Financial Times.

Bumper agricultural yields would initially follow, as crop disease became history. However, farm livestock would slowly starve because they rely on gut bacteria to digest plant material. And soil fertility would begin an inexorable decline, deprived of nutrients because microbes break down organic matter, make atmospheric nitrogen available for plants to take up through their roots, and help weather minerals. In lakes and oceans, the loss of microbes would have more rapid ecological implications. Within a few weeks, most of the food chain, from tiny free-floating animals (zoo-plankton) through to fish, would perish, deprived of the energy generated by photosynthesising algae and bacteria.

The long-term good news is that, in a microbe-free world, we wouldn't have to worry about increasing carbon dioxide and global warming. The not-so-good news should we still be around to notice – is that within a few hundred years, global cycles and systems, disrupted by sterile seas and infertile soils, would bring about more serious changes in atmospheric composition, reducing oxygen levels and probably freezing the Earth's surface from pole to pole.

But the scenario is science fiction. Microbes are survivors. They have been around nearly four thousand million years longer than we have, exploiting every possible way of making a living in every environment where there is liquid water between -5°C and 110°C. Microbes are at least a hundred million million million (10^{20}) times more abundant than we are, with more organisms in a bucket of sea or pond water than there are people on Earth. The total weight of unseen life we share the planet with almost certainly exceeds the visible (but the weigh-in is rather tricky).

We began to appreciate the biodiversity of small organisms in the late 19th century, when researchers started classifying microscopic plants, animals, fungi and 'germs' on the basis of their appearance and simple chemical tests (such as how they are stained by iodine). Then, as now, scientists focused on groups that can be grown in controlled laboratory conditions, usually as single-population cultures, so that their characteristics and properties – whether benign or disease-causing – can be easily studied and measured. But only around 1% of microbes can be persuaded to adapt to life in a Petri dish or a conical flask, and it is only with molecular techniques, based on DNA sequencing, that we have realised the true diversity of microbial life, and the extent of ignorance that remains.

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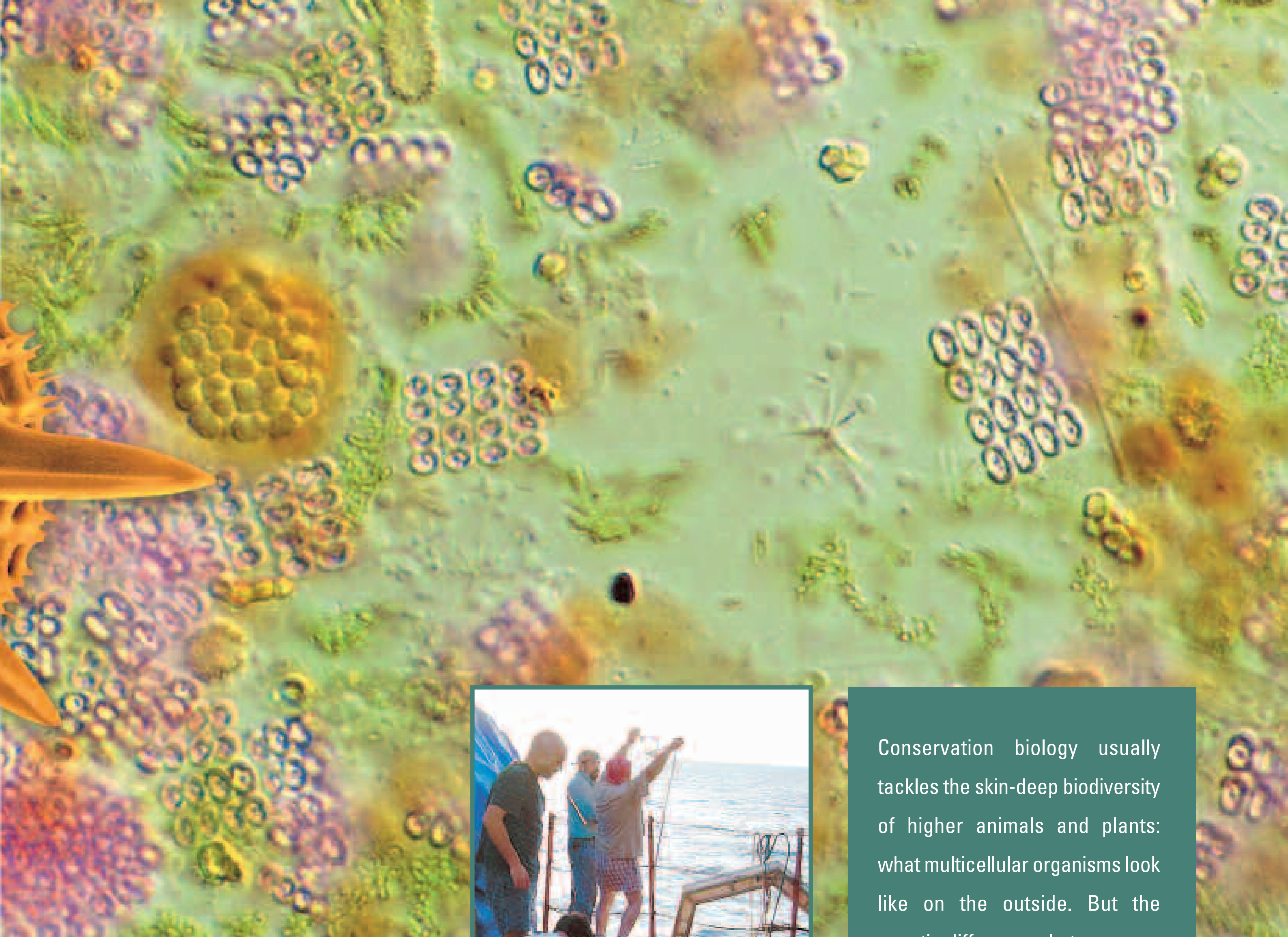
When we think of biodiversity, we usually think of multicellular organisms with their huge variety of different shapes and appearances, for example the many millions of species of insect. But genetically all insects are much the same, and not that different from ourselves and other animals. Major chunks of the human genome are the same as in fruit flies, as well as in chickens, frogs and nematodes. This is because we shared ancestors around 600 million years ago. Single-celled animals and algae have been around three times longer, and microbes without cell nuclei (prokaryotes) around six times longer. That



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doesn't necessarily mean three to six times as many species, but does seem to have resulted in around five times as much DNA diversity, coding for diverse proteins, enzymes and metabolic activities. The range of those activities has made the Earth what it is today.

Between 2000-05, the NERC Marine and Freshwater Microbial Biodiversity programme has supported more than 30 projects investigating biochemical processes and ecological interactions at the micro-scale, for a wide range of organisms in an equally wide range of aquatic environments, from the Arabian Sea and the deep Pacific to the beach at Aberystwyth and a small pond in the Lake District. The main aim explicitly was not stamp-collecting – finding and naming as many new taxonomic groups as possible. Nevertheless, novel microbes are hard to avoid, and we need to know what they are if we are to figure out what they are doing.

The programme discovered a new phylum of marine bacteria (a major group, equivalent in taxonomic terms to mammals, birds, fish and reptiles combined), provisionally identified by research groups at Cardiff and Bristol. Other investigators at the universities of Essex and Reading successfully cultured the first archaea from a non-extreme environment. Archaea look very like bacteria, but are genetically further apart from them than we are from fungi. They are the dominant microbes in very hot, acid or highly salty conditions, and were thought to be the possible ancestors of all life on Earth. However, we now know that archaea evolved more recently than bacteria, and that they may be just as widespread – although very much harder to grow in the laboratory.

Researchers at Stirling and Newcastle have helped to balance the global cycle of

Conservation biology usually tackles the skin-deep biodiversity of higher animals and plants: what multicellular organisms look like on the outside. But the genetic differences between one species of orchid, butterfly or bird and another of the same group are relatively trivial. The bulk of biodiversity on Earth is unicellular – the biochemical spectrum of lower organisms. 'Lower' does not mean less evolved; all organisms that currently exist are equal in that regard. It is the conceit of hindsight (a phrase coined by the evolutionary biologist Richard Dawkins) that humans are evolution's last word, and the conceit of terrestrial giants that only big things that live on land are important for the functioning of the Earth system – and its sustainable management.


BSIP, Alexandre/Science Photo Library

nitrogen, by studying novel nitrogen-fixing proteobacteria. These have been found not only in nutrient-poor tropical seas, where they might be expected, but also in nutrient-rich British estuaries – making it harder to separate human impacts from natural processes. At a smaller scale, scientists at the Marine Biological Association, Plymouth Marine Laboratory, Warwick, and the University of East Anglia have found a new virus genus. This has the largest virus genome sequenced to date, and contains an exceptionally high proportion (86%) of genes that have not been found anywhere else.

The virus work focused on aquatic strains infecting photosynthetic bacteria (cyanobacteria) and microscopic algae (including coccolithophorids, that cause blooms visible from space). Viruses can control the abundance of their hosts, and can also transfer genes between them – natural genetic modification that seems to be important for microbial evolution. When viruses kill their hosts, cell contents spill into the water, contributing to nutrient cycles. This process has implications for climate: firstly because it can change the fate of carbon in the ocean, and secondly because the chemicals released include dimethyl sulphide, a compound that promotes cloud formation when it reaches the atmosphere.

Researchers at the universities of Newcastle and Kent have given particular attention to marine bacteria belonging to the actinomycete group. Similar organisms that we already know about from land produce an unrivalled range of useful bioactive compounds. The new work has shown that marine forms also have considerable pharmaceutical potential, and that information from DNA sequencing can help target the screening process – bringing a new generation of antibiotics (for example, drugs that could control the hospital superbug methicillin resistant *Staphylococcus aureus*) a step closer. For several years, big drug companies have tried to design such bioactive compounds from scratch, but to date they have achieved disappointing returns on their investments.

Microbial behaviour and ecology are also relevant to pharmacology, since interactions between microbes play a major role in turning on (and off) the synthesis and release of key compounds. Work at Heriot-Watt University has shown that marine bacteria use chemical signalling to control their production of antibiotics to fight off competitors. Their defences are only activated when the bacteria grow at high densities on a surface, as a biofilm. Other marine bacteria have evolved the ability to physically disrupt the biofilms of competing organisms. Macro-algae (seaweeds) are even able to eavesdrop on bacterial communications, as discovered at Plymouth Marine Laboratory. In this case, the algae use the bacterial signals as evidence of a suitable settlement surface for the single-celled phase of their own life cycle. Microbial evolution has undoubtedly produced many other sophisticated signal-control systems and 'weapons of micro-destruction', with as-yet-untapped biotechnological opportunities.

In this article, we've only been able to briefly highlight a small proportion of the exciting research carried out by the Marine and Freshwater Microbial Biodiversity programme. The programme formally ends on 31 March 2005, but NERC is continuing to support networking between academic groups and industry, and other ways to use the science. If you want to hear more about the programme, come to our final meetings where we will be showcasing some of the best science. The meetings are open to everyone, and will be held in Edinburgh on 24 May and London on 2 June 2005. For further information, see www.nerc.ac.uk/m&fmb or contact Phil Williamson, email: p.williamson @uea.ac.uk or Ruth Welters, tel: 01793 411604, email: rewe@nerc.ac.uk.

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