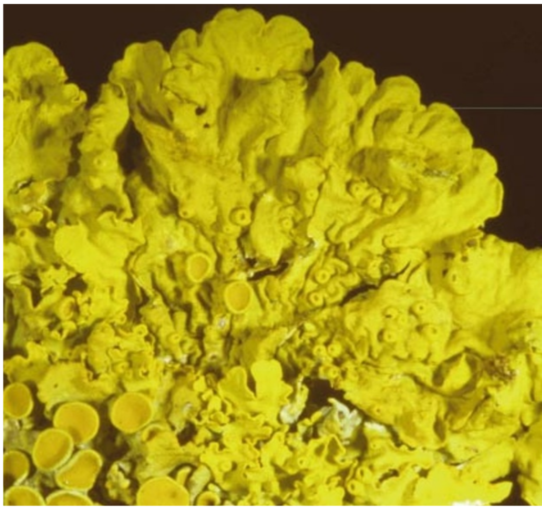
Vital signs

The science of biomonitoring, which uses living organisms as 'sensors' to track environmental pollution, seems to be coming of age. John Whitfield considers its potential.

FRENCH MUSSEL WATCH



PIER LUIGI NIMIS

Telling tales: *Mytilus edulis* mussels (above) and lichens such as *Xanthoria* (right) accumulate chemical pollutants in their tissues.

In the early 1980s, an illegal battery-disposal operation in Hong Kong's Junk Bay was releasing large amounts of polychlorinated biphenyls, lead and zinc into the water. But the crime did not go unwitnessed. The barnacles and mussels living in the bay concentrated the pollutants in their tissues. The evidence they gave up to local researchers and their colleagues at the Natural History Museum in London helped the authorities shut the law-breakers down.

The idea that studies of living organisms can provide information about environmental hazards is not new: before the advent of modern safety equipment, miners kept an eye on the health of caged canaries to warn them of dangerous gas build-ups. But as researchers have concentrated on their own favoured techniques, rigorous standardized methods for biological monitoring have been slow to emerge — success stories like the Hong Kong example are still rare.

Enthusiasts for biomonitoring argue that their field is now coming of age, however. They point to the recent development of protocols that can do much more than simply provide general markers of ecosystem health. In many cases, researchers are now combining ecological studies with analytical chemistry to produce information on the effects of pollution on living organisms, the identity of the chemicals involved, and even where they came from. "In the past few years there's been a considerable drive on the part of the main regulatory bodies to integrate biological and chemical monitoring," says Peter Matthiessen, an ecotoxicologist and director of the UK Natural Environment Research Council's Centre for Ecology and Hydrology in Windermere, Cumbria.

Biomonitoring has long been the poor relation to the straightforward chemical analysis of water, air and soil. Chemical sensors can provide highly accurate readings of environmental pollution. But in some regards, say the proponents of biomonitoring, this precision is spurious. Instruments can quantify the amount of a pollutant present in the environment. But if a pollutant is not taken up by organisms, it may cause little damage to an ecosystem — and the extent to which it is taken up may depend on a range of factors, including climate and acidity. Also, chemical sampling of the environment can only provide a snapshot of what may be a highly dynamic situation, whereas some organisms preserve a continuous record of the environment throughout their lives.

Community values

In the early years of the last century, two German biologists, Richard Kolkwitz and Maximilian Marsson, realized that some freshwater invertebrates were more sensitive to pollution than others — which means that the community of species found at a particular site says much about its cleanliness. In Britain, this technique is used to monitor 7,000 river sites across the country.

Although assessments based on community ecology are good at exposing severe pollution events, they are less useful at providing subtle warning signs that an ecosystem is coming under pressure. "They can only tell you that you've had a major impact after the event," says Matthiessen. But combining ecological observations with chemical measurement of pollutants accumulated by animals and plants can provide a much more sensitive and predictive analysis.

Marine scientists have led the way. In Europe, their work was stimulated by the 1992 Convention for the Protection of the Marine Environment of the North-East Atlantic, known as the OSPAR Convention, to which most European nations are signatories. The OSPAR Convention covers the northeast Atlantic, North Sea and parts of the Arctic Ocean and Mediterranean. Its signatories have pledged to "take all possible steps to prevent and eliminate pollution".

A requirement to monitor the effects of pollutants — including heavy metals, industrial and agricultural chemicals, radioactive waste — and the activities of the oil and gas industries on marine organisms is written into the OSPAR Convention. But as measurements began to accumulate over the 1990s, it ▸

became apparent that the diversity of methods used was preventing useful comparisons.

In 1998, the year in which the OSPAR Convention came into force, the European Union set up a project called Biological Effects Quality Assurance in Marine Monitoring, or BEQUALM, to standardize marine biological monitoring. By the time this project wraps up in October, a network of laboratories in Britain, Norway, Sweden and Germany should have hammered out about half-a-dozen standardized measures. These include the activity levels in fish of enzymes that process trace metals and organic pollutants; pathological analysis of fish livers; and community analysis of planktonic plants and invertebrates living in the seabed. Given the range of techniques involved, the progress towards consensus is no mean achievement, says Matthiessen.

Researchers working on other aspects of biomonitoring are similarly standardizing. "There was a period of total anarchy, when every scientist had his or her own methods," says Pier Luigi Nimis, a botanist at the University of Trieste in Italy who uses lichens to monitor air pollution. He now believes the best methods are emerging "by a process of natural selection".

Italian lichenologists have adopted a dual approach. They have devised an index of lichen biodiversity, and the sampling methods to calculate it, as an indicator of the atmospheric levels of sulphur dioxide and oxides of nitrogen. Coupled with this, the accumulations of 17 trace metals are measured in a single species in each area.

Governments are starting to take notice. ANPA, the Italian environment agency, has launched a lichen-mapping project. And the influential Association of German Engineers intends to submit a slightly modified version of the Italian protocols to the European Committee for Standardization in Brussels for adoption at a pan-European level.

Enthusiasts say biomonitoring is much cheaper than conventional chemical monitoring. Automated chemical sensors are expensive to buy and maintain, says Nimis, and biological approaches can help reveal where best to use them: for example, by revealing pollution hotspots that merit continuous chemical monitoring. "Moving 500 metres can make a big difference," he says.

Steve Hopkin, a zoologist at the University of Reading who is trying to interest the Environment Agency of England and Wales in biomonitoring protocols involving earthworms and woodlice, adds that instruments are vulnerable to theft and vandalism. "If you try to set up an air sampler in an inner city, it's not going to be there for very long, unless you put an electrified fence around it," he says.

> After a period of total anarchy, the best methods are emerging by a process of natural selection.

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Under surveillance: barnacles and mussels have been used to monitor pollution in Hong Kong's waters.

Star quality

As biomonitoring slowly gains credence with regulatory agencies, certain 'indicator' species have emerged as stars. In the sea, the undisputed champion is the blue mussel, *Mytilus edulis*. As mussels filter food from the water they live in, they also retain contaminants, which reach high concentrations in their tissues. Their sedentary lives prevent confusion about where they might have picked up a chemical. They are found in vast numbers all around the northern hemisphere, and they are an important food source for many animals.

Several countries have mussel-watch programmes designed to reveal large-scale, long-term trends. The US Mussel Watch programme, run by the National Oceanic and Atmospheric Administration, was established in 1986. It monitors mussels from 263 sites around the US coastline, focusing on trace metals and organic compounds such as polychlorinated biphenyls and dioxins. Since it began, levels of most synthetic chemicals and of cadmium have fallen, whereas other trace metals have held steady.

In warmer climes, where *M. edulis* does not live, crustacea could become the sentinel organisms of choice. Barnacles in particular, says Philip Rainbow of the Natural History Museum, are "phenomenal accumulators of trace metals". Rainbow advocates the use of 'cosmopolitan' crustaceans with wide distributions, such as the barnacle *Balanus amphitrite*, which has spread around the world by clinging to the hulls of ships.

Rainbow is one of the leaders of the project to monitor barnacles and mussels in the waters of Hong Kong. In addition to fingering specific polluters, the project has recorded the shifting pattern of industry and pollution in the former British colony. Over the 1980s, the focus of pollution moved from Victoria Harbour in the south to Tolo Harbour in the north. In the 1990s, as Tolo Harbour was cleaned up, the distribution of pollutants began to reflect the growing industrialization of the neighbouring part of China.

Valuable though 'indicator' species such as mussels and barnacles are, studies of just one or two organisms cannot reveal everything about an ecosystem. To gain a complete picture of the marine environment, information from a filter feeder such as a mussel should be augmented with analysis from a seaweed, which samples chemicals in solution, and a sediment-dweller such as a worm.

Although most biomonitoring experts are optimistic that the use of such wide-ranging protocols will increase, they note that many regulators are still more comfortable with chemical analyses — which tend to be easier to enforce, and for courts to interpret in the event of breaches of pollution controls. "These things don't change overnight," says Matthiessen. But now that biomonitoring has its foot in the regulators' door, he is confident that its day will come. ■

John Whitfield works in *Nature*'s science writing team.

OSPAR Convention
- **http://www.ospar.org/eng/html/convention/welcome.html**

BEQUALM
- **http://www.cefas.co.uk/bequalm**

Italian lichen protocols
- **http://www.sinanet.anpa.it/aree/atmosfera/qaria/biomonitoraggio/Nimis_Bioindi.asp**

US Mussel Watch
- **http://state-of-coast.noaa.gov/bulletins/html/ccom_05/ccom.html**