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The role of biomarkers in environmental assessment (1). Introduction

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A series of four papers, commissioned by the European Science Foundation, are presented on the state-of-the-art of the use of biomarkers in environmental assessment. These papers are phylogenetically based and cover invertebrates, vertebrates, plants and invertebrate populations and communities.

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Introduction

Over the last few years there has been an increasing interest in the use of biomarkers for environmental assessment. Several books have covered various aspects of the problem. These include an American Chemical Society Symposium (McCarthy and Shugart 1990) which brought together experts from around the world, an evaluation of a wide variety of biomarkers, supported by the Society of Environmental Toxicology and Chemistry (Huggett *et al.* 1992), *Animal Biomarkers as Pollution Indicators* (Peakall 1992), two North Atlantic Treaty Organization Workshops, one on the strategy of using biomarkers (Peakall and Shugart, 1992) and a second on assessing health and environmental impacts of chemicals (Travis 1993) and the *Nondestructive Use of Biomarkers in Vertebrates* (Fossi and Leonzio 1993).

The term 'biomarker' has been gaining acceptance in recent years, albeit with some inconsistency in definition. Here we define biomarkers as 'a biological response to a chemical or chemicals that gives a measure of exposure and sometimes, also, of toxic effect'. The levels of 'biological responses' that can be considered range from the molecular to community structure and even to the function and structure of ecosystems. While this reflects the fact that pollutants can exert their influence at all levels it does result in a definition of biomarkers that is too broad for some but it is difficult to define a point at which the term 'biomarker' should be replaced by another term such as 'ecological indicator'. In this series of papers the focus is largely on biochemical biomarkers and the extent to which links can be established at different levels of biological organization.

The European Science Foundation (ESF) is an association of 54 research councils, academies and institutions in 20 countries. The role of the ESF is to bring together European scientists to work on topics of concern, to share expertise and to coordinate the use of facilities. The scientific work sponsored by the ESF includes basic research in the natural, medical and social sciences.

The European Science Foundation commissioned four papers on the use of biomarkers in environmental assessment based on phylogenetic considerations. These are on invertebrates (Depledge and Fossi 1994), vertebrates (Peakall and Walker 1994), terrestrial plants (Ernst and Peterson 1994) and invertebrate populations and communities (Lagadic *et al.* 1994). A primary interest of the ESF is to ascertain to what extent biomarkers can be used in the assessment of environmental 'damage' and in the formulation of regulations to control such damage.

The authors were requested – each for their specific area – to give the basic concepts, state what they would like to be able to do with biomarkers in environmental assessment, where the field is now in relation to this ideal and what is the way forward. They were also asked to tackle the definition of 'damage'. These papers were discussed at an ESF Working Group meeting in the Camargue in September 1993 and modified in the light of these discussions. They have subsequently been subjected to the normal peer-review process and are now published together in *Ecotoxicology* in order that they may reach a wider audience. Feedback from readers, either to the individual authors or to this author of this summary is welcomed.

A major reason for the current interest in biomarkers is the serious limitation of the classical approach to environmental toxicology, that of measuring the amount of the chemical present, either in the organism or the environment and relating that, through animal experiments, to adverse effects. On the exposure side of the equation there are difficulties, especially in terrestrial systems, of knowing how much of the material is actually bioavailable, for example, heavy metals in soils and exposure of wild vertebrates to pesticides. Then there is the problem of the toxicity of complex mixtures, the composition of which vary both spatially and temporally from their source. On the toxicity side there are serious difficulties in extrapolating from laboratory to field conditions. There are problems of marked differences in interspecies sensitivity and there are many ecological factors that can confound the results.

The need for biomarkers is heightened by the desire to extend environmental assessment. The concept of life cycle assessment (LCA) of chemicals is currently attracting a good deal of attention and requires that a wide range of tests are available. The implementation of LCA is severely limited by its most critical component – namely ecological risk assessment. The concept of LCA and the problems of providing adequate tests are discussed in the paper by Depledge and Fossi (1994).

Limitations of current environmental management procedures have been discussed by numerous authors. In particular, questions have been raised about the extent to which laboratory tests alone are or ever will be capable of predicting either the likely exposure or the effects of chemical pollutants on ecosystems (Cairns 1983, Kimball and Levins 1985, Cairns and McCormick 1992, Depledge 1992).

One approach that can assist in handling the problems outlined above is the use of biomarkers. The types of biological responses that can be measured range from the molecular, through to effects on the intact organism, to population, community structure and, perhaps, the structure and function of ecosystems. Three basic points can be made about this continuum. Firstly, the time scale increases, moving from seconds or minutes to years or even decades. Secondly, the importance increases (we are obviously more concerned if the function of ecosystems are affected than over molecular changes) and, lastly, it becomes increasingly difficult to relate effects to cause as one moves up this continuum.

Although 'damage' is not a technical word it is difficult in an environmental context to achieve a working definition. The Oxford Dictionary defines damage as 'injury, harm, especially physical injury to a thing such as impairs its value or usefulness'. Later, damage is defined in legal terms as 'the value, estimated in money, of something lost or withheld; the sum of money claimed or adjudged to be paid in compensation for loss or injury sustained'.

From these definitions it is clear that damage means that there has been sufficient impairment that loss has been caused. Recently there has been considerable effort made, especially in North America, to put a cash value on environmental damage. A notable case in point is that of the *Exxon Valdez* disaster. Putting a financial value on environmental damage is fraught with difficulties and many would prefer not to try, but it is an integral part of whether or not damage is 'acceptable'. A recent report by the UK Joint Nature Conservation Committee (Farmer and Bareham 1993) on the environmental implications of UK sulphur emission policy estimated the area of sites of special scientific interest (SSSIs) that would remain at risk with 60, 70, 80 and 90% reductions of sulphur emissions from the 1980 baseline. This report was concerned only with the number and area of SSSIs that would be at risk, it did not discuss the cost implications.

It is, however, impossible to avoid cost implications. The slogan 'The polluter pays' is, like most slogans, dangerously simplistic. In most cases the polluter passes on the cost; certainly this will be the case in power generation. Thus, society has to decide how much reduction of sulphur emissions it is prepared to pay for.

A consideration of 'damage' can be divided into two areas. The first is the proof that injury is occurring and that it can be linked to a specific cause. The second is whether or not this damage is acceptable.

Biomarkers can play a valuable role in assessing whether or not damage is occurring. Potentially toxic substances are now globally distributed and the question is 'are they causing harm?'. One way of answering that question is to ascertain whether or not organisms living in a specific area are physiologically normal. This would be equivalent to the expectations of a medical check-up for a group of workers from a chemical factory. The concept of using physiological normality outside highly contaminated areas as a criterion was put forward by Peakall (1992) and is discussed further in the paper by Peakall and Walker (1994).

Another approach is to say that organisms living in a specific area should not show *irreversible* physiological changes. The essence of this concept is that a distinction should be made first between homeostatis (physiological normality), an area where the organism is capable of compensation to the stress and, second, when the limit of compensation is reached. The concept originally put forward in considerations of occupational human health by Hatch (1962) has been modified for environmental considerations by Depledge (1989) and is discussed further by Depledge and Fossi (1994). The difficulties with this approach lie in proving whether or not changes are reversible and whether reversible changes may lead to irreversible damage, for example, damage to DNA can be repaired, but the damage may already have started alterations to the system that will lead to irreversible harm.

Similar considerations apply when we consider communities or ecosystems. Such organizational units have their normal, sustainable functions (analogous to homeostatis or physiological normality of the individual organism) and again we need to protect against change or certainly irreversible change to these functions.

A critical component of any discussion of 'damage' is not scientific, but rests on the opinion of society. How much damage are we prepared to tolerate? Or, more bluntly, how much are we prepared to pay to prevent or to repair that damage? Once such a framework is decided it is possible to put into place a scientific basis for environmental assessment: without it it is impossible.

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