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Viewpoint

The "bioeffect assessment index" (BAI) A concept for the quantification of effects of marine pollution by an integrated biomarker approach

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Abstract

The "bioeffect assessment index" (BAI) is based on the integration of several pathological endpoints measured in the liver of European flounder (*Platichthys flesus* (L.)) during a long term study of biological effects of pollution in the German Bight. The BAI represents a modification of the "health assessment index" since it includes solely validated biomarkers reflecting toxically induced alterations at different levels of biological organisation in order to quantify the effects of environmental pollution. The concept of the BAI is based on the observation of progressive deleterious effects from early responses to late effects. Specific "key events" were detected, representing progressive stages of functional deterioration. The biomarkers selected from a whole battery of cellular markers for the BAI calculation reflect deleterious effects of various classes of contaminants such as heavy metals, organochlorines, pesticides, PAHs, and therefore reflect general toxicity in an integrative manner. Selected biomarkers were: lysosomal perturbations (reduced membrane stability), storage disorders (lipid accumulation) as early markers for toxic effects of liver cells, and the size of macrophage aggregates and their acid phosphatase activity. The latter two markers are indicative for the modulation of non-specific immune response which represents longer time scale responses after chronic exposure.

Keywords: Environmental health; Index; German Bight; Flounder; Biomarker; BAI; HAI

1. Main objectives

Increasing disease prevalence (Dethlefsen et al., 2000), tumour frequencies (Koehler, 2004) and disturbances of reproductive success (von Westernhagen et al., 1981) including feminisation of males are only a few examples for the fact, that coastal areas are heavily impaired. The central question is: How to quantify biological effects and include these informations into an integrated risk assessment approach? Concepts which combine both, comprehensive information about the wide range of biological effects and easy applicability and accessibility of reliable test assays are badly needed (Bernstein and Weisberg, 2003; Schiff et al., 2002). These concepts should comprise information on the extent of toxically induced degradation of environmental quality such as acute pollution events and their recovery as well as acute and chronic exposure to complex mixtures of pollutants.

Monitoring "environmental health", the quality status of marine life conditions especially in coastal areas, requires reliable tools to demonstrate the effects of anthropogenic impact on biological systems. The term "environmental health" is used in this context because the evaluation of changes in ecosystems shares common features with the standard approaches of human medicine. The development of early warning indicators, risk

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approaches and tests of ecosystem fitness parallels closely developments in health sciences. While long-term effects at higher biological levels such as the population and ecosystem level have a much higher economic and ecological relevance, responses at the molecular and cellular level are rapidly detectable and highly specific for the environmental effects of contamination. In order to analyse the extent of disturbances of a biological system and to quantify the actual state, the integration of several biomarkers at different levels of biological organisation has been discussed by several authors (McCarthy and Munkittrick, 1996; Attrill and Depledge, 1997; Allen and Moore, 2004) as one of the most promising concepts. Results obtained from studies at the molecular and cellular level do not automatically allow predictions of stress responses at higher levels such as communities. Only, when the emergent properties of a system are fully described, a selection of variables at lower levels can be undertaken (Kerr, 1976). Thus, only a biomarker that is verified and calibrated in this way can be used as a valid bio-indicator, in case its response coincides with responses at the community level (McCarthy and Munkittrick, 1996). Therefore, integrated biological effects monitoring should comprise the implementation of different biomarkers which reflect pollution-induced effects at several levels of the biological organisation (see also Cairns, 1991).

The present concept is based on two large data sets on biomarker responses obtained from individual flounder (*Platichthys flesus*) of the German Bight and the Baltic Sea over a time period of 7 years. These data bases were available to implement a strategy for the integration of several biomarkers of biological effects in this fish species based on the health assessment index (HAI) devised by Adams et al. (1993), providing a quantitative index that allows statistical comparisons of "fish health" from different data sets. For this purpose a suite of biomarkers applied in the present study was analysed in each individual animal in order to define the physiological status of pollution-induced stress at various organisational levels.

2. Strategy and results

2.1. Questions

- Is it possible to define the physiological status of pollution-induced alterations by a suite of validated biomarkers at different levels of organisation on an individual basis?
- Is a progression of these alterations detectable by the biomarker response?
- How can different biomarker responses be integrated and combined and these datasets are compared?
- Is it possible to quantify responses to "environmental deterioration" using an integrative biomarker index?

2.2. Biomarker selection

Biomarkers can be divided into markers of *exposure* and *toxic effects*. Biomarkers of *exposure* represent responses such as induction or inhibition of specific enzymes involved in biotransformation and detoxification as a consequence of chemical exposure. In most of the cases, these responses are early biomarkers for specific toxicants at a low level of biological organisation, the molecular or cellular.

The advantages of *biomarkers of exposure* are their early response and their specificity of reaction. The latter may also be regarded as disadvantageous since the complex contamination situations are not reflected. Thus *biomarkers of exposure* are useful for the monitoring of hot spots of pollution or clearly defined point source inputs as well as for the characterisation of chronic unknown chemical input.

Biomarkers of toxic effects reflect pathological endpoints and are determined at each level of the biological organisation. In contrast to the *biomarkers of exposure* these effects mostly cannot be attributed to the impact of single contaminants and therefore serve as integrative markers of complex toxicities.

The advantages are the high ecological relevance of biomarkers at high levels of organisation (individual, population and community level) and the general picture of the status of environmental deterioration that can be obtained by applying this kind of biomarkers. The disadvantage is that in most of the cases the quality of contamination remains speculative.

Therefore, only a combination of both kinds of biomarkers provides sufficient information for the assessment of responses reflecting the quality *as well as* the quantity of environmental deterioration.

The following biomarker data are integrated in the present study (Fig. 1).

2.2.1. Molecular level

As a biomarker of exposure at the molecular level the activity of the cytochrome P 450-dependent monooxygenase EROD (Phase I of the biotransformation system) was analysed. The measurement of the activity of mixed-function oxygenases as a measure of increased activity of the biotransformation system is suited well to detect exposure to classes of organic pollutants such as co-planar PCBs, polyaromatic hydrocarbons, planar dibenzodioxines (CCD) and dibenzofurans (CDF) (Stegeman and Hahn, 1994; Goksoyr et al., 1996; Bucheli and Fent, 1995; Livingstone et al., 1993; Förlin, 1980).