CONCEPTS AND APPLICATION OF INTEGRATIVE BIOINDICATORS FOR ASSESSING EFFECTS OF STRESS ON FISH HEALTH

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EXTENDED ABSTRACT ONLY-DO NOT CITE

Environmental stressors such as contaminants can cause a variety of biological responses in fish ranging from the biomolecular and biochemical to population and community-level effects. To assess fish health, the bioindicators technique utilizes a suite of biological responses both as integrators of stress effects and as sensitive response (early-warning) indicators of existing and past environmental conditions (Adams 1990). Short-term indicators, such as biomolecular and biochemical responses, and longer-term ecologically relevant indicators, such as population and community responses, are included in this approach to provide measurement endpoints that can be used in environmental management or in the regulatory decision and ecological risk assessment (ERA) process.

Biomarkers of environmental stress at lower levels of biological organization such as the mixed function oxidase (MFO) enzymes and DNA integrity provide direct evidence of exposure to stressors while intermediate-level responses such as histopathological, bioenergetic, immunological, and reproductive changes can help predict stress effects at the individual, population, and community levels. Responses at the lower levels of biological organization have the primary advantage of being relatively sensitive (short-term response) to stressors thus serving as early warning indicators of impaired fish health. Conversely, responses at higher levels of organization (populations, communities) are relatively insensitive (long-term response) to stressors but have higher ecological relevance and are therefore more directly applicable to the ERA process and for addressing environmental management and regulatory issues (Fig. 1). Biomarkers, however, cannot be considered useful bioindicators of fish health unless they are causally linked to

ecologically relevant responses such as population or community-level endpoints (McCarty and Munkittrick 1996) .

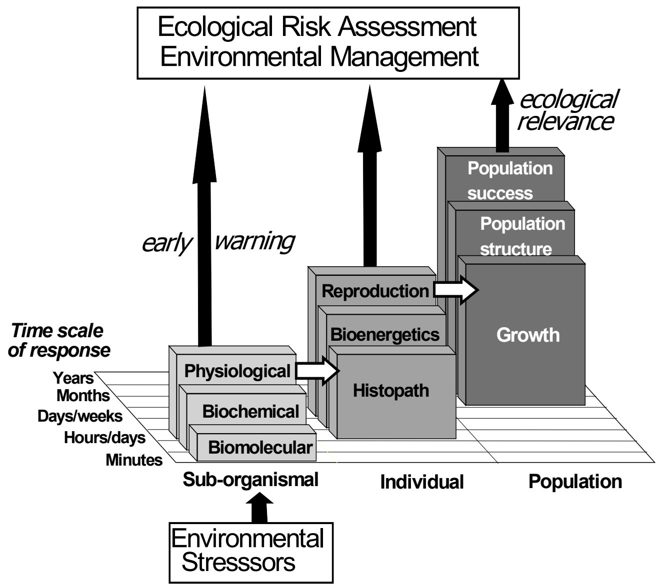

Figure 1. Hierarchical responses of organisms to environmental stressors illustrating the sensitive early-warning responses at the lower levels of biological organization

(biomarkers of contaminant exposure) and the slower-responding but ecologically relevant responses at the higher levels of organization (bioindicators of effects) (modified from Adams and Greeley, 2000).

To determine possible causal relationships between lower (i.e. biomarkers) and higher level effects, responses in fish populations at several levels of biological organization were measured along a downstream gradient in a contaminated stream. The downstream response patterns for several biomarkers along this contaminant gradient were similar to higher-level response patterns indicating that these biomarkers could be potentially useful in the ERA process because of their sensitivity and relationships to ecologically relevant endpoints.
A suite of biomarkers and bioindicators were also used to demonstrate biological recovery over several years in a contaminated stream following environmental cleanup activities. Short-term response indicators such as the MFO enzymes and physiological parameters provided early indications of recovery, while the longer-term and slower-responding indicators (i.e., population, community indices) demonstrated delayed improvements in health. Using all the individual biomarker and bioindicator responses together in a multivariate discriminant analysis procedure provided an integrated assessment of fish health and identified a reduced set of measurement endpoints most responsible for distinguishing between stressed and healthy fish populations. Depending on the particular system and the types of stressors involved, only 4-7 response variables were needed to assess recovery and discriminate between healthy and unhealthy systems. These distinguishing variables generally represent different levels of biological organization and functional dynamics in organisms including MFO enzymes, organ dysfunction, bioenergetic, and reproductive competence. These results illustrate the importance of utilizing multiple-response endpoints at different levels of biological organization when assessing the health and recovery of organisms exposed to multiple environmental stressors.

Proper experimental design of bioindicator-based field studies involves measurement of responses which (a) range from the biomolecular/biochemical level (e.g., biomarkers of exposure) to the population and community levels (bioindicators of effects, (b) represent responses along gradients of both ecological relevance and response time (reflecting degrees of sensitivity) (Fig. 1), and © include measurements of both specific and nonspecific responses. Biomarkers, however, cannot be considered bioindicators of effects unless they are causally linked or related to ecologically relevant responses such as reproductive, population, or community level endpoints. Understanding mechanisms of stress response by establishing relationships between exposure biomarkers and bioindicators of effects should provide for more informed environmental regulatory decisions regarding ecosystem integrity and the effectiveness of cleanup activities.

Application of biomarkers and bioindicators in environmental stress studies involves measuring a suite of selected stress responses at each of several levels of biological organization in order to (1) assess the effects of environmental stressors on organisms, (2) predict future trends (early warning indicators of change), (3) obtain insights into causal relationships (mechanisms) between stress and effects at higher levels of biological organization, and (4) evaluate the effectiveness of remedial (cleanup) actions. Application of biomarkers and bioindicators in field studies are not without their limitations (Table 1), even though they may be most effectively utilized within an integrative framework to assess the health of fish populations.

Table 1. Major features of biomarkers and bioindicators relative to their advantages and limitations for use in field bioassessment studies.

Major Features	Biomarkers	Bioindicators
Types of response	Subcellular, Cellular	Individual Through Community
Indicators of	Exposure	Effects
Sensitivity to stressors	High	Low
Relationship to cause	High	Low
Response variability	High	Low-Moderate
Specificity to stressors	Moderate-High	Low
Time scale of response	Short	Long
Ecological relevance	Low	High

References

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