CURRENT CHALLENGES IN CONTAMINANT EFFECTS MONITORING:

MULTIPLE STRESSORS AND ECOLOGICAL SIGNIFICANCE

S. Marshall Adams and Kenneth D. Ham
Environmental Sciences Division,
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6036
(423)574-7316/fax:(423)576-8543/sma@ornl.gov

Multiple Stressors and Causal Relationships

Aquatic ecosystems are complex entities that are controlled and regulated by a multitude of physicochemical and biological processes. In addition, aquatic organisms experience a variety of natural and man-induced stressors, both of which vary spatially and temporally. The high variability in environmental factors combined with synergistic and cumulative interactions of these factors in aquatic ecosystems complicate the interpretation and evaluation of the effects of contaminant-related stressors on organisms.

Responses of organisms to environmental conditions are the integrated result of direct and indirect contaminant impacts, natural environmental stressors (e.g., varying temperature and hydraulic regimes, sediment loading), or a combination of both natural and man-induced perturbations. Correlating specific contaminant-related responses at the lower levels of biological organization (i.e., biomolecular/biochemical) to effects at higher levels (e.g., growth, reproduction) is difficult because of the physicochemical and biological complexity of most aquatic systems. Natural processes operating in the food web such as interspecific and intraspecific competition, predator-prey relationships, and density-dependent interactions could have major influences on the nature, magnitude, and final expression of a contaminant response in fish populations. In field situations, however, experimental conditions are difficult to control, and evaluation of causal relationships is generally circumstantial in nature, being based primarily on the weight of evidence approach (Suter et al., 1994). Also, in a natural field situation, the responses of organisms to environmental stressors, particularly at the higher levels of biological organization, are integrative in nature reflecting the totality of the environmental conditions that impinge upon them (Colby, 1984; Ryder and Edwards, 1985).

Because of the complexity of natural systems, many approaches have failed to include many of the factors necessary for assessing the effects of environmental stressors on aquatic ecosystem health. To help minimize some of the limitations of field studies in assessing cause and effect between stressors and biological responses, studies should also include factors that are useful for evaluating and interpreting the integrated health responses of these organisms. For example, nutrition and feeding, habitat influences, competition, and other noncontaminant-related parameters such as temperature, varying hydrologic regimes, and turbidity could all be important factors influencing the nature and magnitude of organism responses to environmental stressors. Therefore, an attempt should be made to account for these factors when evaluating the relative contribution of contaminants on the health of aquatic organisms.

Regulating Mechanisms

Environmental stressors such as contaminants can affect fish populations and communities by two basic pathways or mechanisms. Direct mechanisms occur primarily through metabolic effects that are initiated at the lower levels of biological organization. Indirect mechanisms however, operate mainly through effects on the food chain and on the behavior of organisms (Adams, 1990). The effects of pollutants on organisms via direct mechanisms occur initially at the molecular or subcellular level and can be expressed, for example, as increases in mixed function oxidase (MFO) enzyme activity or DNA damage (Thomas, 1990). Responses at this level can be propagated upward through increasing levels of biological complexity and affect physiological and metabolic processes such as lipid dynamics, immunocompetence, and hormone regulation (Larsson et al., 1985). Ultimately, these effects may be manifested as changes at the population and community level. In addition, pollutants may impact organisms indirectly through the food chain by influencing the quality (energy and protein content) and quantity (biomass) of energy available to consumers. Behavior, in turn, can be influenced by contaminants impairing reproductive, feeding, or habitat selection activities (Reynolds and Casterlin, 1980). The more ecologically relevant parameters of aquatic systems, such as organism growth, reproduction, and population-level attributes, can therefore be affected by both direct and indirect mechanisms of contaminant stress and include the integrated effects of metabolic impairment, energy availability, and behavioral alterations (Adams, 1990).

A helpful approach for achieving a better understanding of the relative importance of direct and indirect mechanisms in evaluating the responses of fish populations to environmental stressors is to measure a selected suite of stress indicators representing three major categories of response indicators (Table 1). These three categories are (1) direct indicators of contaminant exposure which include the MFO enzymes and DNA damage, (2) direct indicators of pollutant effects that primarily reflect metabolic dysfunction such as serum enzymes and measures of lipid dynamics, and (3) indirect indicators of pollutant effects including nutrition and feeding indices, certain histopathologic indicators, and various measures of lipid pools within the organism.

Table 1. Major categories of contaminant response indicators and some representative parameters within each category that could be used in environmental stress studies to help evaluate the relative importance of direct and indirect mechanisms in influencing stress responses of fish populations.

Direct indicators of toxicant exposure	Direct indicators of metabolic dysfunction	Indirect indicators of exposure
MFO enzymes	Serum enzymes (organ dysfunction)	Nutritional/Feeding
Bile metabolites		Growth
DNA damage	Lipid metabolism	Lipid pools
Body burdens of pollutants	Immunocompetence	Bioenergetic parameters
Selected histopathology -various necroses	Selected pathologies -macrophage aggregates	Bile color
Oxidative enzymes -peroxidases		Serum lipids (triglycerides and cholesterol)

Early Warning Signals of Environmental Stress

Hatch (1962) formulated a hypothesis for pollutant monitoring in the context of occupational health concepts applied to humans. The situation described is similar to the challenges faced by ecotoxicologists in evaluating the effects of contaminant effects on wildlife species. The essence of Hatch's hypothesis, later modified by Depledge (1989), is that a distinction should be made between departures from normal physiological and behavioral responses which reflect the normal health state and the consequences of this departure from health (Fig. 1). Starting with normal individuals, contaminant exposure results in a progressive deterioration in health and may be ultimately fatal resulting in the demise of entire populations. Early departures from the healthy state are associated with the initiation of compensatory responses with little change in disability. Additional impairment beyond the compensation limit becomes associated with increased disability and overt disease. With additional environmental challenges the survival potential of organisms already operating within the compensatory zone declines because of their decreased ability to respond to these challenges. Beyond the limit of compensation, it is unlikely that any response to additional environmental challenges could be successfully mounted. Provided, however, that environmental conditions improve sufficiently and quickly enough, an organism may be able to recover and repair damaged systems and restore compensatory responses. Monitoring impairment of behavioral and physiological responses should provide an early warning of the onset of disabilities (Depledge 1989). On the disability scale, measures of contaminant effects are usually not detected until after the loss of compensation while on the impairment scale contaminant effects are detected much earlier and can be reversible and curable.

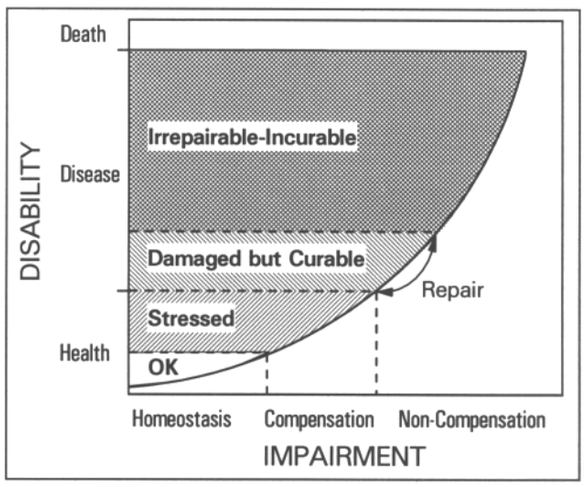

Figure 1. Concept of evaluating disability and impairment relative to early warning of stress in fish.

This concept, therefore, of evaluating disability and impairment in organisms experiencing environmental stress should provide a basis for early detection of stress and give appropriate warning signals of impending damage to organisms, populations, and communities before irreversible damage occurs. This concept of evaluating disability and impairment can also serve as a basis for establishing decision criteria relative to acceptable levels of pollution (Depledge 1989).

In summary, some main challenges facing those concerned with assessing the effects of environmental contaminants on organisms are (1) the influence of multiple stressors on stress responses in biological systems, (2) determining causal relationships between various levels of biological response to stressors, and (3) identifying early warning indicators or measures of organism impairment that have biological significance before irreversible or serious disability occurs. In all these areas, the health of biological systems (from the individual level to the population and community levels) has as its basis the physiological performance of the organism. Therefore, aspects of contaminant effects monitoring which include physiological measures of health should not only be utilized as measures of deviations from normal function, but should also be applied in the larger context of helping to understand multiple stressor effects, causal relationships between different levels of biological response, and early warning indicators of biologically significant effects.

References

Adams, S. M. 1990. Status and use of biological indicators for evaluating the effects of stress on fish. Amer. Fish Soc. Symp. 8: 1-8.

Colby, P. J. 1984. Appraising the status of fisheries: Rehabilitation techniques. pp. 233-257. In V. W. Cairns, P.V. Hodson, and J.O. Nriagu, (eds), Contaminant effects on fisheries. John Wiley and Sons, New York.

Depledge, M. 1989. The rational basis for detection of the early effects of marine pollutants using physiological indicators. Ambio 18:301-302.

Hatch, T. 1962. Changing objectives in occupational health. Ind. Hyg. J. Jan.-Feb. 62:1-7.

Larsson, A., Haux, C., and Sjobeck, M. 1985. Fish physiology and metal pollution: results and experiences from laboratory and field studies. Ecotoxicol. Environ. Saf. 9: 250-281.

Reynolds, W. W., and Casterlin, M. E. 1980. The role of behavior in biomonitoring of fishes: laboratory studies. pp. 59-82 In C.H. Hocutt, and J.R. Stauffer, (eds.), Biological Monitoring of Fish. Lexington Books, Lexington, MA.

Ryder, R. A. and Edwards, C. J. 1985. A conceptual approach for the application of biological indicators of ecosystem quality in the Great Lakes Basin., Great Lakes Fisheries Commission International Joint Committee, Windsor, Ontario.

Suter, G.W., Sample, B. E., Jones, D. S., and Ashwood, T. L. 1994. Approach and Strategy for Performing Ecological Risk Assessments for the U.S. Department of Energy's Oak Ridge Reservation, ES/ER/TM-33/R1, Oak Ridge National Laboratory, Oak Ridge, TN.

Thomas, P. 1990. Molecular and biochemical responses of fish to stressors and their potential use in environmental monitoring. Amer. Fish. Soc. Symp. 8: 9-28.