Ecological Risk Assessment in the United States: Methodologies and Practices

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Abstract

This presentation will outline three approaches developed in the United States for assessing ecological risks. The methods have been offered by the National Research Council, the Water Environment Research Foundation, and the US Environmental Protection Agency. Similarities and differences among these frameworks will be discussed. Several issues that challenge the future advancement and implementation of these methodologies are highlighted in the context or risk-based decision making

1. Introduction

An ecological risk is the probability that an undesired ecological event will occur, combined with an evaluation of its consequences. Ecological risk assessment integrates ecology, environmental chemistry, environmental toxicology, hydrology, and other earth sciences to characterize undesired human impacts on ecological resources (Bartell, 1996a). The following sections briefly describe three approaches, with emphasis on the proposed USEPA methodology, for assessing ecological risks in the United States. Several issues of concern in advancing capabilities in assessing ecological risks are outlined.

2. Frameworks for Ecological Risk Assessment

Ecological risks are assessed in the U.S. mainly as the result of environmental laws. Yet, there is no methodology currently sanctioned by the government for assessing ecological risks. This reflects in part the realization that ecological systems are in many ways unique; each assessment provides specific technical challenges. Any reluctance of environmental scientists to standardize assessment methods is not unexpected. The following presentation outlines three general methodologies for assessing ecological risks.

2.1 *National Research Council Framework*

In 1989, the National Research Council (NRC) convened a Committee on Risk Assessment Methodology. The Committee developed a framework that integrated ecological risk assessment within the existing NRC framework for human health risk assessment (Barnthouse, 1993). The resulting NRC ecological risk framework consists of hazard identification, exposure assessment, exposure-response assessment, and risk characterization. Hazard identification determines if a particular stressor requires detailed scientific study or immediate risk management. The Committee defined exposure assessment as determining the extent of contact with the stressor. Exposure-response assessment determines the relation between the magnitude of exposure and the degree of the ecological effect. Risk characterization describes the magnitude of the risk, including uncertainties. Emphasis was placed by the NRC on expressing the risks in terms easily understood by decision makers and the public. Research, validation, and monitoring are emphasized in all phases of the NRC risk assessment methodology.

2.2 *Water Environment Research Foundation Approach*

The Water Environment Research Foundation (WERF) sponsored the development of a three-tiered methodology to assess ecological risks posed by chemicals in aquatic systems (Parkhurst, 1993): Tier 1, screening-level risk assessment; Tier 2, risk quantification using existing data; and Tier 3, risk quantification requiring new data.

The WERF methodology at each tier consists of problem definition, source characterization, exposure assessment, ecological receptor characterization, ecological effects characterization, risk characterization, and risk management. Problem definition parallels the hazard identification of the NRC methodology. Source characterization identifies the chemicals of concern in the assessment. The exposure assessment identifies the pathways of transport and quantifies the expected environmental concentrations (EECs) of contaminants. The exposure assessment also delineates the distribution and environmental fate of the chemicals and assists in identifying ecological resources potentially at risk. Individual species or aquatic communities are included in the assessment as the result of characterizing the ecological receptors. In the ecological effects characterization, pollutant concentrations that produce adverse effects on the ecological receptors are estimated for each chemical of interest. Risk characterization compares the EECs with the criteria pollutant concentrations.

3. *USEPA Framework*

The Framework for Ecological Risk Assessment was developed by the United States Environmental Protection Agency (USEPA) to foster consistency in ecological risk assessment within EPA, identify key technical issues, and define terminology " (Norton et al., 1993). To EPA, ecological risk assessments "evaluate the likelihood that adverse ecological effects will occur ... as a result of human activities..." (Norton et al., 1993). The current USEPA framework for ecological risk assessment identifies problem formulation, exposure analysis, effects assessment, and risk characterization as the necessary components of an ecological risk assessment. The following sections briefly describe the USEPA Framework for Ecological Risk Assessment (USEPA, 1992).

3.1 *Problem formulation*

The problem formulation phase delineates the nature and scope of the assessment, characterizes the source of potential ecological risks, identifies ecological resources at risk, and produces a conceptual model outlining the overall assessment. Success in problem formulation requires interaction among risk managers and risk assessors.

1) *Characterizing the stressor*

Ecological stressors can be physical, biological, or chemical in nature. Examples of physical stressors include logging, draining wetlands, erosion, and converting natural lands to agriculture. Biological stressors include, for example, the invasion of exotic species, pest outbreaks, and introduction of genetically engineered organisms. Chemical stressors include pesticides, herbicides, fungicides, fertilizers, toxic metals, and other compounds introduced to the environment.

In formulating an ecological risk assessment, risk managers and risk assessors are particularly interested in determining the timing, frequency, magnitude, and duration of the stressor. These aspects of temporal scale determine if a stressor is an isolated event (e.g., spill), a periodic phenomenon (e.g., fertilizer applications), or continuous (e.g., chronic industrial pollution).

Relevant spatial scales of the stressor are also important. The stressor might be extremely local, perhaps ranging in distribution from several square meters to several hectares. Other stressors may become distributed over much larger geographic regions (e.g., acid deposition, radionuclide fallout). The magnitude of the stressor is combined with its relevant spatial and temporal scales to profile the stressor. The stressor profile provides information for identifying ecological resources potentially at risk.

2) *Ecological effects*

In ERA, an ecological effect is selected as a focus for risk estimation. The effects of physical, chemical, or biological stressors can be measured at different levels of biological and ecological organization. Ecological responses include effects on physiological processes, individual organisms, populations, communities, ecosystems, watersheds, and landscapes; assessments routinely address effects at several levels.

3) *Conceptual Model*

The current framework specifies a *conceptual model* as the end product of the problem formulation phase (USEPA, 1992). This model prescribes a recipe that relates all phases of the assessment. That is, the model should identify the nature of the stress, identify ecological resources potentially at risk, consider quantitative relationships between the stressor and the ecological responses, use this information to pinpoint data needs, identify methods and models, outline how all this information will be integrated to produce the assessment, and finally, describe how the assessment results will contribute to the risk management process.

3.2 *Exposure assessment*

Exposure is determined by the mechanisms that bring organisms into contact with the stressor(s) and is assessed by quantifying the frequency, magnitude, and duration of such contact. The ecological effects of concern will largely determine the quantification of exposure to toxic chemicals relevant to estimating risks. The geographical distribution, life history, growth dynamics, and behavior of selected assessment species will specify the important spatial and temporal scales over which exposure (and dose) should be quantified.

3.3 *Ecological effects and stress-response relationships*

As previously mentioned, diverse ecological responses to stressors can be the focus of risk assessment. Estimating the relationships between exposure, dose, and response constitutes the next important phase of ecological risk assessment. The laws of physics and chemistry determine the environmental activity of chemical stressors; organic matter merely presents substrate and a complex array of biochemical reactions that may be blocked or altered kinetically by the xenobiotics. The biological or ecological level of organization selected to assess the impacts of altered reactions is largely a matter of the convenience of measuring and significance of the potential impact.

3.4 *Risk characterization*

Risk characterization integrates the stressor profiles (e.g., exposure concentration for toxic chemicals) with the stress-response relations to estimate ecological risks. Risk characterization importantly extends beyond basic impact assessment by quantitatively incorporating the uncertainties inherent to risk estimation, and evaluating their potential impacts on risk estimation.

The results of risk characterization, including uncertainties, enter into the risk management process. The risk manager(s) determine if the results are useful and consistent with the overall assessment objectives, particularly regarding choices among management alternatives. If decisions are possible, the risk assessment may stop at this point. If not, the risk assessment process can be repeated until a management alternative can be selected. Coincident with all phases of the assessment is the acquisition of additional data, verification of the analyses, and monitoring.

4. Critical Issues in Ecological Risk Assessment

Several issues must be resolved to advance the development and application of ecological risk assessment methodologies.

4.1 *Concept of "environment"*

Throughout the development of ERA , there has been an implicit reference to "the natural past" (i.e., Power-Bratton, 1992) as one underlying model for "the environment" in the broader sense. This or any other reference environment (e.g., Holling, 1986) has not been described in sufficient detail to facilitate meaningful assessments. Lacking a prescription for the kind (i.e., quality, quantity) of environment that is the goal of protective mandates, risk assessors cannot make best use of their ecological or quantitative skills. If ecological risk assessment is to realize its full potential in characterizing probable human impacts on the environment, a clearer description of "environment" is required.

4.2. *Ecological scale and complexity*

Many site-specific ecological risk assessments focus on relatively small spatial scales, where it is often possible to assess risks accurately and precisely. However, approaches that usefully address smaller scale "waste site" compliance criteria may prove ineffective in assessing larger scale environmental stressors (e.g., acid precipitation, climate change). Such needs will hopefully stimulate novel solutions for larger scale risk assessments.

Ecological stressors, whether point or non-point sources, operate on complex landscapes. Larger watersheds (e.g., the Chesapeake Bay) encompass agricultural, urban, and undeveloped lands, as well as industrial facilities, that jointly produce complex effluents (e.g., agrochemicals, organic contaminants, domestic and industrial wastes). Currently, risk assessors cannot forecast the combined impacts of, for example, increased fertilization, increased sedimentation, temperature change, and additions of organics and metals on the production dynamics of aquatic ecological systems. Substantial fundamental research and development is necessary to acquire the necessary understanding to make such forecasts.

4.3 *Value of ecological resources*

Valuation of ecological resources has proven to be one of the most difficult aspects of ecological risk assessment. Ecological resources have ecological, economic, and societal values. Yet, assigning values to ecological resources remains difficult using traditional ecological or economic models (Peet, 1992).

Assigning purely ecological value to natural resources proves challenging: species have no inherent ecological value. Species appear to fill functional roles vacated by taxa at risk. Thus, without knowing the future states of nature (in the absence of stressors), assessing purely ecological values might not be possible. However, one primary ecological concern (i.e., value) lies in sustaining the life support capacity of ecological systems potentially at risk.

5. Ecological Risk and Decision Making

Remediation based on target chemical concentrations may force clean-up to exceed rational expectations in some cases, while failing to protect ecological resources in other instances. A temptation exists to impose more stringent standards as detection levels decrease. The net result can be costly clean-up activities that provide ever diminishing returns in reduced risk and environmental protection per additional dollars spent. Risk-based remediation provides the framework for establishing acceptable levels of risk in relation to other activities that determine current or planned environmental quality in the region (Bartell, 1996b).

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