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Stress to indicator species as assessment endpoints*

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Abstract

The use of indicator species as assessment endpoints for ecological risk assessment provides a basis for a scientifically valid extrapolation from measurements to those impacts which are of primary importance to environmental decision makers and managers. Assessment endpoints should be chosen on the basis of ecological significance, economic importance, or regulatory significance. Indicator species, to be useful as assessment endpoints, must perform an ecologically significant function as well as being sensitive to chemical induced stresses to the ecosystem. In this paper, we will examine how indicator species can be utilized as assessment endpoints within an integrated logical framework for ecological risk assessment.

1. Introduction

The use of indicator species, organisms whose abundance, distribution, and status may be correlated with gradients of environmental stress, has been a long established practice in ecological hazard assessment. Surrogate species are employed in ecotoxicological studies as stand-ins for trophic assemblages in naturally occurring communities. While some effort is made to choose surrogates on the basis of their presumed importance to natural communities, in reality, choices are often made on the basis of convenience in performing laboratory bioassays or the belief that the most sensitive organisms are being tested. Test results are then extrapolated to the "real world" in a bottom up, *ad hoc*, approach to characterizing the perceived danger to natural communities. Thus surrogates are employed as de facto endpoints for ecological risk assessment.

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A substantial body of literature exists on single or multiple species indicators of specific environmental contaminants [1–3], but there appear to be few guidelines for selecting indicators or for establishing selection criteria. This problem is especially acute when attempting to monitor natural areas for signs of changes in status. Kremen [4] presents a method for selecting groups of indicators by using ordination methods to establish indicator properties of groups of organisms and selecting subsets for more intensive monitoring.

In this paper, however, we will examine a new structural framework for ecological risk assessment which provides a context for the use of indicator species as assessment endpoints. Unlike the use of surrogates, the employment of the top down approach mandated by the new paradigm provides a logical framework for the integration of indicator species into the risk assessment process. We will explore the relationship between indicators and endpoints, and present a rationale and a procedure for choosing indicator species as assessment endpoints.

2. New approaches to ecological risk assessment

The complexity of ecological systems and the need to evaluate the responses of ecosystems to natural and anthropogenic perturbations has highlighted the need for new approaches to ecological risk assessment. Any such theoretical context for ecological risk assessment must satisfy a number of stringent requirements imposed by the variety and complexity of ecological risk assessment problems:

- The framework must provide the capability to address complex ecological questions at all levels of ecological organization.
- The framework must provide a mechanism for defining objectives and identifying endpoints.
- The framework must provide for feedback in the decision making process.
- The framework must be sufficiently flexible to incorporate new assessment methodologies.

One such paradigm has been adopted recently by the United States Environmental Protection Agency as "A Framework for Ecological Risk Assessment" [4, 5]. This ecological risk assessment paradigm, illustrated in Fig. 1, is divided into three phases and provides for a structured, iterative approach to establishing regulatory objectives, building conceptual models, selecting endpoints, and characterizing risk in terms of assessment endpoints.

The scope and objectives of the ecological risk assessment, so called "regulatory endpoints", provide the operational constraints for the risk assessment process. These primary endpoints reflect societal valuations placed upon natural resources or environmental protection goals incorporated into such regulations as the Endangered Species Act or the Toxic Substances Control Act. They are input into the Problem Formulation phase, shown in Fig. 2, in the form of legal mandates, policy objectives, or management plans.

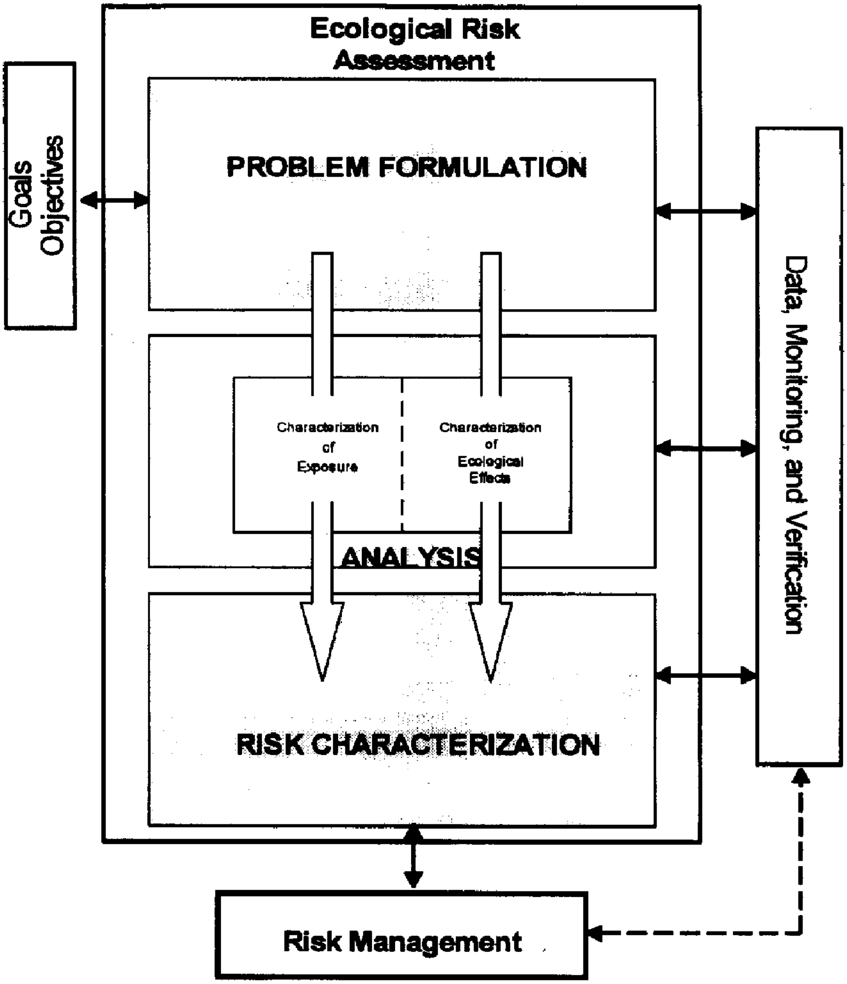

Fig. 1. The ecological risk assessment paradigm.

Problem Formulation distills these broad goals into a series of operational objectives for the risk assessment and formulates a procedure for implementation. The objective of this phase of the risk assessment process is to combine what is known of the characteristics of the stressor and the ecosystem potentially at risk into one or more conceptual models. The model defines the ecosystem components potentially at risk, plausible exposure scenarios, and hypotheses concerning the manner in which the chemical stressor will impact various ecosystem components. The model provides a framework from which appropriate assessment and measurement endpoints may be selected.

3. Ecological endpoints

Assessment endpoints [6–8] define the adverse impacts of primary concern which can be directly linked to the "regulatory" endpoints or management

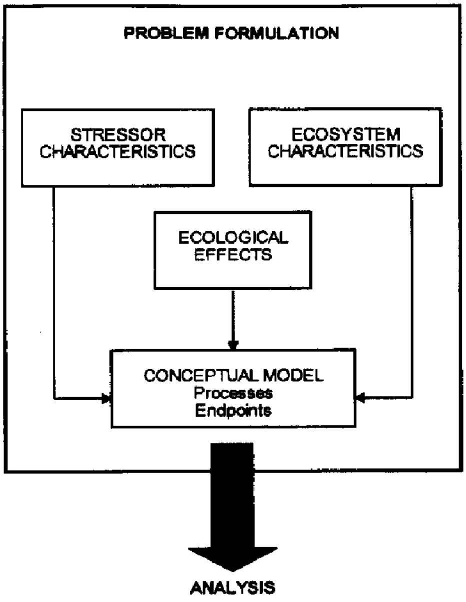

Fig. 2. Problem formulation phase of ecological risk assessment.

objectives. Measurement endpoints are actual data used in the assessment. An example of an assessment endpoint is the reduction in numbers (population) or total weight (biomass) of a species of plant or animal of regulatory interest. Generally this is often interpreted to refer to fish in the aquatic environment or perhaps, one or more endangered species.

In general, assessment endpoints are selected to represent system characteristics or behavior that may be easily linked to regulatory or policy goals. They are biological impacts of primary importance or value and therefore of great significance in the assessment process. Assessment endpoints are selected on the basis of biological relevance and representative of some value which is of regulatory significance. These are integrated biological or ecological impacts of primary ecological importance to the maintenance of populations or the structure and function of communities and ecosystems. Ideally, an assessment endpoint should integrate both direct and indirect impacts of the chemical stressor. The risk will ultimately be expressed in terms of the consequences to the assessment endpoints and demonstrated relevance to regulatory endpoints. In summary, assessment endpoints should possess the following characteristics:

- Ecological significance.
- Regulatory significance.
- Economic or societal value.

A distinguishing feature of ecological risk assessment is the frequent necessity to utilize more than a single endpoint to characterize risk to populations or communities. Depending on the objectives of the risk assessment, endpoints may be selected from one or more of the hierarchical levels of ecological organization. Figure 3 illustrates some examples of the assessment endpoints

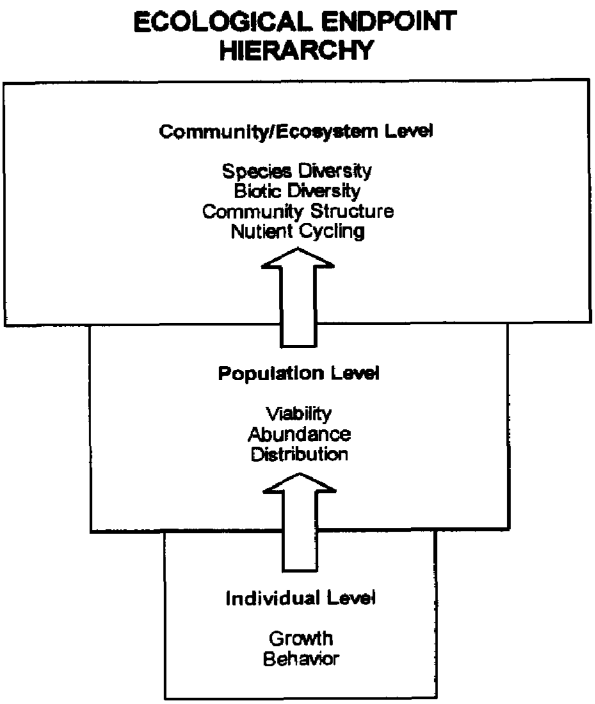

Fig. 3. Assessment endpoints at each level of the ecological organization hierarchy.

which may be used at each level of the ecological organization hierarchy. For example, growth, mortality, and behavior provide good indicators of the status of individual organisms, while changes in the abundance or distribution of species are useful endpoints at the population level. Population level endpoints are especially significant for risk assessment because many species have great economic value or have assumed regulatory significance under such laws as the Endangered Species Act or the Marine Mammal Protection Act.

4. Indicators and endpoints

Implicit in the discussion of endpoints is the assumption that the endpoints chosen for risk assessment are indicators of response to chemical stressors. That response may be direct, as when an organism is exposed to the stressor, or indirect, when the assessment endpoint is influenced by other changes in the community or ecosystem. Thus it is not surprising that characteristics of useful ecological indicators mirror those describing assessment endpoints [8].

- Indicators should possess intrinsic importance to the structure or function of the community or ecosystem: The indicator is the endpoint. This is characteristic of so-called "keystone" species.
- They should be relevant to regulatory or policy objectives: The so-called regulatory endpoints. Examples are commercially valuable species or those with Threatened or Endangered status.

- They should serve as sensitive early warning indicators of stress on the system. Such indicators should respond rapidly to the presence of chemical stressors.

5. Ecological indicator selection criteria

To fully realize the potential of indicator species as assessment endpoints requires the systematic application of a set of selection criteria to potential indicator choices. While many different criteria could be identified for specific assessment circumstances, Kelly and Harwell [9] describe some generally applicable guidelines:

- Sensitivity to stressor — Indicators with a high signal-to-noise ratio are preferable, as they provide a high level of response per unit of stress.
- Rapidity of response to stress — A rapid response is necessary to provide the early warning characteristic. Such responses generally occur at lower trophic levels among populations with short life cycles, such as phytoplankton.
- Specificity of response — Indicators which respond only to specific chemical stressors provide the mechanism for demonstrating causal stressor–response relationships.
- Ease and economy of measurement — While desirable, this criterion should not be elevated to primary importance in the selection process.
- Relevance to assessment goals — This provides additional support for the rationale of selecting indicator species as assessment endpoints. It underlies the necessity of answering the "so what" question fundamental to risk characterization.

Finally, the effective use of population level endpoints requires the availability of sufficient data to characterize the life histories of the species of interest, define the dose–response relationships for all identified endpoints, and to describe the fundamental population dynamics of the indicator species. Population dynamics models for species of interest are valuable supplements to available data.

The procedure outlined above for identifying and selecting assessment endpoints and indicator species is summarized in Fig. 4. The selection process is driven from the top down with the principal constraints being the objectives and the "regulatory endpoints". For population level assessments, candidate assessment endpoints are chosen and then filtered for specific indicator properties and for availability of sufficient data to support the assessment. It is unrealistic to assume that any single indicator would meet all the selection criteria or that all preferred assessment endpoints would possess exemplary indicator properties. Thus it is common to identify additional indicators along with those chosen as assessment endpoints.

This practice provides a means of addressing the "so what" question frequently encountered in ecological risk assessment. The most sensitive indicator

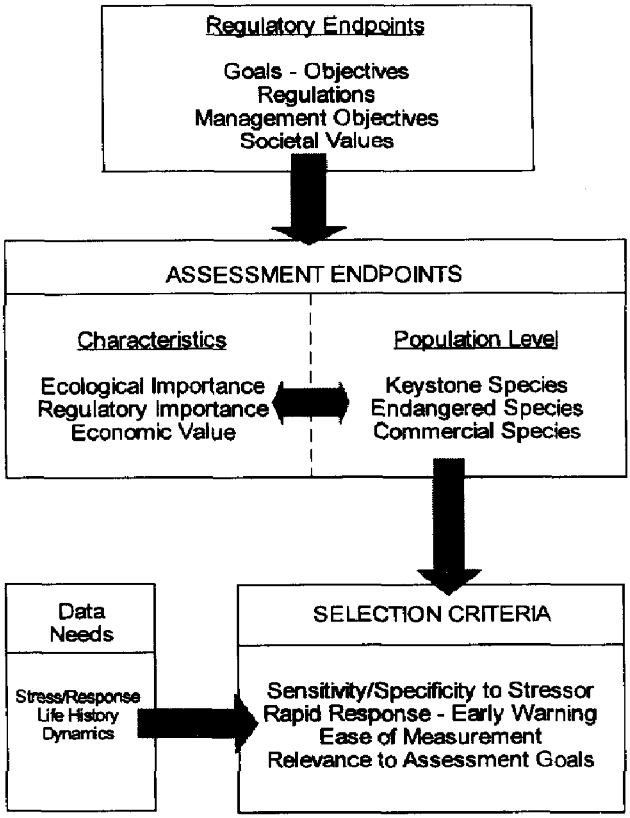

Fig. 4. Selection process for using indicator species as assessment endpoints for risk assessment.

populations often have only marginal value as assessment endpoints while suitable endpoints may not be sensitive to the chemical stressor; hence the "so what". However, the endpoint population may be dependent upon the indicator species as a food source and thus the indirect effects may influence the level of risk to the assessment endpoint to a far greater extent than would be predicted on the basis of direct toxic effects alone.

6. Characterizing ecological risk

The challenge of ecological risk assessment is to assemble endpoints, indicators, and stressor–response hypotheses into an integrated logical framework for characterizing risk. This task has been greatly facilitated by the use of simulation models which are capable of projecting the complex dynamics of interacting populations. Models offer a number of advantages for ecological risk assessments. Models provide virtually the only means to simultaneously couple multiple endpoints and indicators into a logical framework corresponding directly to the conceptual model. Models can project the status of

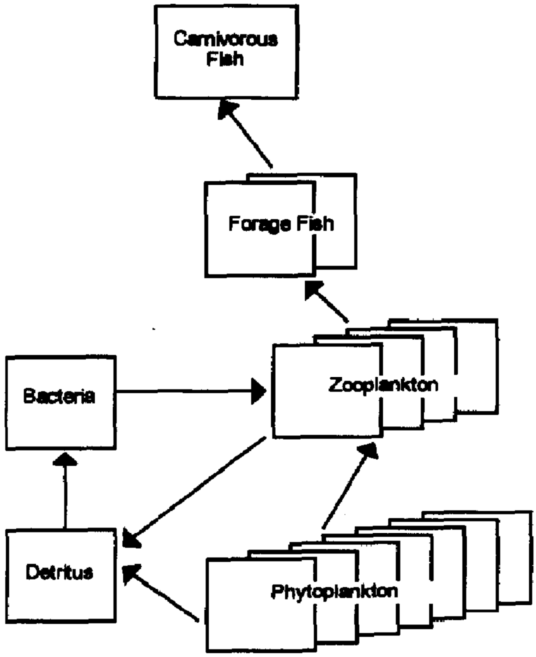

Fig. 5. Structure of the pelagic food web of a typical temperate zone lake.

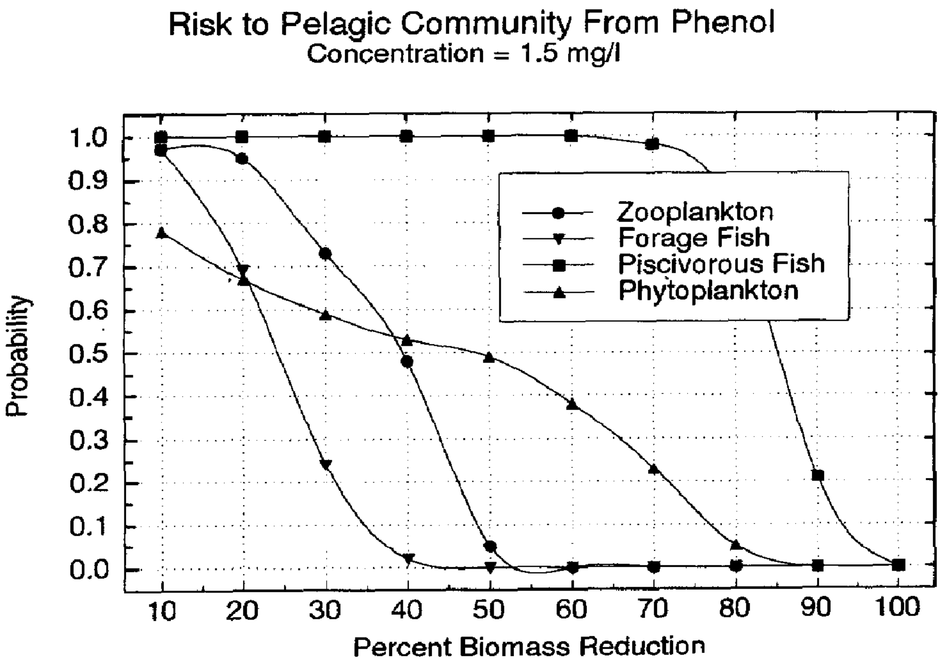

Fig. 6. Predicted risk to selected indicator populations from exposure to phenol.

assessment endpoints resulting from both direct and indirect toxic effects and express impacts in terms suitable for economic valuation studies [10].

A number of new methodologies have been developed, using Monte Carlo simulation, to obtain probabilistic estimates of adverse impacts to assessment endpoints [11, 12]. Consider the example shown in Fig. 5, which represents the pelagic food web in a typical temperate zone lake. While all of the species in this system are adversely impacted by exposure to a chemical substance such as phenol, only the carnivorous fish compartment is likely to meet the criteria for assessment endpoint status. The reason is that the top carnivore in this system is typically the largemouth bass (*Micropterus salmoides*), a valuable sport fish. However, the other compartments can serve as indicator species from which indirect effects can be projected onto the largemouth bass population dynamics. Figure 6 illustrates the simulated impact of phenol exposure on the major components of the pelagic food web. Both direct and indirect effects are modeled and risk is expressed as the probability of a given percentage reduction in the biomass of a compartment [13]. It is clear that at this exposure level, there is a high probability of a biomass reduction exceeding 80 percent for the largemouth bass compartment. Other simulations, at different exposure levels, can be directly compared to this result to explore regulatory options.

Conclusion

We have outlined an integrated approach to ecological risk assessment for populations which provides a logical basis for identifying assessment endpoints and indicator species. Using the conceptual model as metaphor, endpoints and indicators are combined with data to produce probabilistic risk estimates for relevant regulatory and societal endpoints.

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