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Individuals versus Organisms versus Populations in the Definition of Ecological Assessment Endpoints

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ABSTRACT

Discussions and applications of the policies and practices of the U.S. Environmental Protection Agency (USEPA) in ecological risk assessment will benefit from continued clarification of the concepts of assessment endpoints and of levels of biological organization. First, assessment endpoint entities and attributes can be defined at different levels of organization. Hence, an organism-level attribute, such as growth or survival, can be applied collectively to a population-level entity such as the brook trout in a stream. Second, assessment endpoints for ecological risk assessment are often mistakenly described as "individual level," which leads to the idea that such assessments are intended to protect individuals. Finally, populations play a more important role in risk assessments than is generally recognized. Organism-level attributes are used primarily for population-level assessments. In addition, the USEPA and other agencies already are basing management decisions on population or community entities and attributes such as production of fisheries, abundance of migratory bird populations, and aquatic community composition.

Keywords: Assessment endpoint Population Community Organism Level of organization

THE ISSUE

Assessment endpoints are used to explicitly define the environmental values of concern and provide the focus for analysis and characterization in ecological risk assessments (USEPA 1998). Because they are so central to ecological risk assessments, the development of consistent, common terms to describe and discuss assessment endpoints is a worthwhile endeavor. The language used to define ecological assessment endpoints has been controversial. Two recent U.S. Environmental Protection Agency (USEPA) documents have served to highlight the controversy: a set of generic endpoints for ecological risk assessment (USEPA 2003) [summarized by Suter et al. 2004] and a staff paper on risk assessment practices (USEPA 2004) [summarized by Dearfield et al. 2004]. Comments on the latter document in particular, which was developed in response to industry comments on USEPA's risk assessment practices, reveal that the concept of ecological assessment endpoints and the agency's policies on choosing endpoints are still misunderstood.

In this article, we address only the definition of assessment endpoints. At least as controversial is the appropriate estimation of exposures, which greatly influence the degree of conservatism and realism in the risk estimates produced. Challenges include addressing the uncertainty associated with the sparse data sets often encountered in many screening-level assessments, the appropriate spatial areas over which to sum or average exposure, and how to weight different parts of the landscape based on organism, population, or community usage, especially because landscape attributes are likely to change over time. These exposure issues are left for future discussions, but we note they can best be resolved by beginning with a clearly defined focus for the assessment—the assessment endpoint.

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This article attempts to clarify the concept of assessment endpoints in the hope of correcting the misinformation and bad practices that persist in the literature. It addresses 3 related issues: (1) the failure to recognize that assessment endpoints consist of an entity and an attribute and that those components may be defined at different levels of organization; (2) the unfortunately common practice of using "individual level" when referring to the organism level of biological organization, which leads to statements that the Agency's risk assessments are intended to protect individuals; and (3) the dismissal by some ecologists of endpoint entities or attributes defined below the population level of organization and the failure to recognize population-level entities when they are associated with organism-level attributes.

LEVELS OF ORGANIZATION

To begin, it is useful to clarify what we mean by levels of biological organization. Endpoints can be clearly distinguished by their attributes.

Suborganismal levels—Examples of attributes at these levels include histopathologies and enzyme activities. These levels are not discussed further, because they are not generally used as ecological assessment endpoints.

Organism level—Examples of attributes at this level include survival, growth, and fecundity. Gross anomalies also are often included as attributes of organisms that reduce their quality (e.g., fish with gross lesions or tumors do not have acceptable recreational or commercial quality, and birds with deformed bills are unacceptable to birders).

Population level—Examples of attributes at this level include abundance, production (e.g., production rate of biomass or harvestable organisms), and extirpation.

Community level and higher—Examples of attributes at these levels include taxa richness, absolute or relative abundance (e.g., trees per hectare or proportional abundance of native species), dominance, production (e.g., net primary production), and area

(e.g., area of a plant community type). They are not discussed further because they generally are not controversial.

ENDPOINT ENTITIES AND ATTRIBUTES

Controversy about assessment endpoints occurs because people confuse assessment endpoints, endpoint attributes, and endpoint entities. It is important to remember the formula:

$$\text{Assessment endpoint} = \text{Attribute} + \text{Entity}$$

Examples are provided in Table 1.

Hence, attributes at each level of biological organization can occur in 1 individual entity (an individual organism or an individual population) or in multiple entities (the organisms in a population or multiple populations within a region).

An attribute at 1 level of organization can be applied to an entity at a different level of organization. For example, death can be an attribute of an organism (e.g., death of an individual bird), to the set of organisms in a population (e.g., 50% mortality of horned larks in a field), or to a community (e.g., 50% mortality of birds in a field). However, the application of an organism-level attribute to a population or community of organisms does not make it a population-level or community-level attribute. Population and community responses are not simply sums of organismal responses. For example, the decline in population abundance is not simply the proportional mortality, because of compensatory and depensatory effects of density on survival, fecundity, or susceptibility to disease and predation (Fairbrother 2001).

Failure to distinguish the attribute and the entity can lead to confusion about levels of organization. For example, participants at a recent workshop argued about whether the incidence of mortality is a population-level endpoint or an organism-level endpoint. It is an organism-level attribute (i.e., organisms die) summarized for a population-level entity (i.e., incidence is the rate of occurrence in a population). The potential for that sort of confusion is the reason that the guidelines from USEPA (2003) on generic endpoints explicitly describe the application of organism-level attributes to assessment populations and communities.

The relationships of entities and attributes can be clarified by comparing risk assessment endpoints for humans and ecological entities (Table 2). Human health risk assessments are intended to protect organism-level attributes of individual humans (e.g., a 2×10^{-5} cancer risk to the reasonable maximally exposed individual), but health risk assessments often also consider risks summed across the members of an exposed population so as to elucidate the magnitude of potential effects (e.g., an incremental risk of 4 cancers in an exposed population of 200,000). In contrast, ecological risk assessments seldom use entities at the organism level. Rather, organism-level attributes typically are associated with an assessment population or community (USEPA 2003). True population-level attributes are not considered in human health risk assessments because individuals are to be protected, and an effect on a human population sufficient to lower its abundance or production would not be countenanced. However, in ecological risk assessments, risks to abundance, production, extirpation and other attributes of nonhuman populations or sets of populations are assessed.

INDIVIDUAL-LEVEL VERSUS ORGANISM-LEVEL

Note that "individual" is not a level of organization (check any biology text); it is a term denoting singularity: an individual organism, an individual population, etc. In ordinary speech, it is commonly used to denote a person. Thus, when ecological risk assessors refer to the "individual-level" as a level of biological organization, they are using nonstandard scientific terminology. This usage occurs in many contexts including some older USEPA documents.

Readers of this article may dismiss this substitution as just a semantic issue; however, we have found that the mixing of the common English usage with the nonstandard technical usage has lead to confusion. In particular, some commentaries on the USEPA's current ecological risk assessment practices use the term "individual" in a way that is not used in the cited report (USEPA 2004) and is misleading. For example, DeMott et al. (2004) stated that the current USEPA approaches "are intrinsically related to predicting potential risks to individuals" and rely "only on individual-based approaches." This usage of the word "individual" implies that the agency treats individual fish, birds, insects, and other biota like humans; i.e., like individual persons. That is not the case, but it is the sort of confusion that can result when "individual" is used to denote both a level of biological organization with certain attributes and a singular entity. Hence, the use of "individual" to denote a level of biological organization is nonstandard terminology that makes a difference.

ORGANISMS, POPULATIONS, AND CURRENT PRACTICE IN THE USEPA

Current USEPA guidelines regarding selection of ecological assessment endpoints are presented in USEPA (2003) and are summarized here with respect to organism and population attributes and entities. Readers should be aware that individual decision makers in the USEPA are informed by

Table 1. Examples of ecological assessment endpoints with entities and attributes defined at different levels of biological organization

1. Growth of a brook trout at the edge of an effluent's zone of initial dilution.
An organism attribute associated with a hypothetical individual organism in a specially protected population.
2. Growth of brook trout in Short Creek.
An organism attribute associated with the organisms in an assessment population.
3. Production of the brook trout population in Short Creek.
A population attribute associated with an individual assessment population.
4. Average production of brook trout populations in Maine.
A population attribute associated with a set of populations.

Table 2. Examples of assessment endpoints for human and ecological risk assessments

Entities	Human health risk assessment	Ecological risk assessment
Organism-level attributes		
An individual organism	Probability of death or injury (e.g., risk to the maximally exposed individual)	Probability of death or injury (e.g., risk to an individual of an endangered species); Seldom used
A population of organisms	Frequency of death or injury, numbers dying or injured	Frequency of mortality or gross anomalies, average reduction in growth or fecundity
Population-level attributes		
An individual population	Not used	Extirpation, production, or abundance
A set of populations	Not used	Seldom used (e.g., extinction rate or regional loss of production)

these guidelines but are not constrained by them. That is, guidelines, as their name implies, mark a policy path that can be confidently followed by a decision maker in most cases, but they do not have legal standing and do not prevent a decision maker from determining how the laws and regulations should apply in a specific case.

Organism attributes are seldom applied to individual organisms. Rather, they more frequently are applied to the organisms in an assessment population or community. Organism attributes combined with population-level entities are the most common ecological risk assessment endpoints in USEPA practice (USEPA 2003) and in most ecological risk assessments world-wide (based on the experience of the authors), particularly in assessments of toxic risks. This practice is well supported by law, policy and precedent (USEPA 2003). Ecological risk assessments based on organism attributes have been upheld by the courts. They are practical, because they can be estimated from standard toxicity tests without level-of-organization extrapolations. They are commonly assumed to provide protection for population attributes. That is, if survival, fecundity, and growth are not decreased in an assessment population, the abundance and production of that population are unlikely to be decreased. However, if survival, fecundity, or growth of organisms are affected, it is not possible to assume proportionate changes in population level attributes (e.g., abundance and production) because of multiple feedback loops and compensatory or depensatory mechanisms. Nevertheless, acting on the assumption that organismal effects will result in some demonstrable population changes will reduce the probability of making a Type II error in a management decision (i.e., assuming that no effect will occur when, in fact, it does). Unfortunately, assessors often do not clearly identify the population or community to which the organism-level attributes are applied, thereby contributing to the misunderstanding surrounding assessment endpoints.

True population attributes are less often used. When they are, they are usually applied to individual populations, although occasionally they may be applied to a set of populations. For example, risks to the set of trout populations in Adirondack lakes were assessed in the National Acid Precipitation Assessment (Baker et al. 1990). Endpoints based on population attributes are supported by policy and precedent (USEPA 2003). However, their responses are more difficult to predict than organism-level responses because of demographic and compensatory or depensatory processes. They may be measured in the field and exposure–response relationships derived from the field observations may be used to estimate ecological risks (Barnthouse et al. 2003). In fact, it is often easier to measure a population attribute, such as abundance or density, in the field than an organism attribute such as mortality or fecundity. Population attributes are useful for many assessments, particularly when populations of harvested species are at risk or when the level of population response is important to the decision (e.g., setting harvest quotas for fishing seasons, as is done by the National Marine Fisheries Service).

In many cases, more than 1 assessment endpoint with attributes at more than 1 level of organization will be used. An example might be an assessment of risks to a salmon population from entrainment in hydroelectric turbines that estimates the proportion of salmon fry killed and also changes in returning salmon abundance. In both of those endpoints, the entity is the salmon population.

SUMMARY AND PROSPECTS

When defining assessment endpoints, it is necessary to consider the appropriate levels of biological organization of both the entities and the attributes. In practice, most ecological risk assessments address organism-level attributes of a population or community. Examples include fecundity of bluegill sunfish in a pond or mortality across all fish species in a watershed. Risks to individual organisms are seldom considered except in the case of endangered species or species with special protection status (e.g., bald eagles under the Bald Eagle Protection Act). Risks to attributes of individual populations or sets of populations are assessed when their importance to the risk management decision justifies the additional effort and uncertainty.

Although assessments of risks to population attributes are becoming more common, community attributes are used more commonly than population attributes in ecological assessments in the United States. This is largely because of the adoption of community metrics for assessing biological integrity under the Clean Water Act (i.e., biocriteria). It is also the result of, in part, the fact that, in most cases, legislative goals are broader than protection of a particular species population (e.g., protecting biotic integrity). Decisions that

commonly involve population-level assessments include protection of fisheries (i.e., setting allowable harvest rates) or wildlife populations (e.g., the Partners in Flight program that protects songbirds under the Migratory Bird Treaty Act). Some regulatory assessments, such as those for cooling water intakes under Sec. 316b of the Clean Water Act, have been based routinely on risks to attributes of fish populations. Thus, assessment endpoints based on population-level attributes are already used when the regulatory context is appropriate.

Hence, despite continued complaint about the USEPA's supposed protection of "individuals," most ecological assessment endpoints use populations or communities as entities with organism-level attributes, many use community entities with community attributes, and an increasing number use population entities with population attributes.

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