Ecological Risk Assessment

Draft Report

Selection and Ranking of Endpoints for Ecological Risk Assessment

Submitted To:
Exposure Assessment Group
Office of Research and Development
U.S. Environmental Protection Agency

Submitted By:
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3202 Monroe St., Rockville, MD 20852
Work performed under contract #68-02-4199

EPA 0811

Ecological Risk Assessment

SELECTION AND RANKING OF ENDPOINTS FOR ECOLOGICAL RISK ASSESSMENT

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Contract No. 68-0224199

September 30, 1988

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SELECTION AND RANKING OF

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I. SELECTION OF ENDPOINTS

A critical step in the performance of an ecological risk assessment is the endpoint selection process. Ideally, the process should focus on ecosystem-level, community-level, and species-level endpoints, using a wide variety of endpoints from all three levels and incorporating a broad spectrum of individual species. Limitations in resources and time, however, naturally restrict the endpoints and species to be selected to a small representative sample. It may then be necessary to further narrow selected endpoints based on practical considerations. Cost and resource limitations could be dealt with by using a tiered testing approach. When species-level tests provide the most practical measures available, they may serve as a first level of testing, indicating the potential for ecosystem effects. If ecosystem-level effects are indicated, these would then be tested through microcosm and mesocosm tests. Finally, if necessary, field tests could be initiated.

Irrespective of the test scheme being used, it is necessary to prioritize the endpoints to be measured. It thus becomes critical for an investigator to be able to identify those endpoints that would be most sensitive to the effects of a pollutant on a system and most predictive of ecosystem stress.

The selection of appropriate endpoints is not a trivial matter. It is not possible to produce a simple delineation of ideal endpoints for a general type of ecosystem or a general category of pollutants. Appropriate endpoints can only be selected with a knowledge of effects of a particular pollutant, the nature of pollutant loading, and the critical features of the impacted ecosystem. The choice of endpoints measuring ecosystem function, for example, can be based on factors such as pollutant loading, pollutant levels, and mechanisms of toxicity. The choice of endpoints measuring ecosystem structure or community-level effects can be determined with knowledge of the kinds of species impacted and the nature of community interactions. The choice of species-level endpoints would be based on factors such as pollutant persistence, pollutant levels, pollutant bioaccumulation, and mechanisms of toxicity. Finally, the choice of species and parts of the environment to examine can be made based on knowledge of pollutant loading, species exposure, and species susceptibility.

Although it is not currently possible to produce specific recommendations for endpoints to be selected, it is possible to provide general guidelines for selection. The discussion that follows presents these guidelines as a series of questions, which are then followed by a collection of endpoint ranking tables. The questions are designed to provide focus on the categories of endpoints and the kinds of species that would be most appropriate to monitor in each particular situation. Each of these questions is described in terms of the kinds of variables that need to be considered in a given ecosystem. The questions are then summarized in an Endpoint Selection Chart.

The Endpoint Selection Guidelines section is organized into two parts. The first group of questions is directed towards selection of appropriate ecosystem-level, community-level, and species-level endpoints. The second group of questions is directed towards selection of appropriate groups of organisms to monitor. The ordering of the group of questions is not absolute. It is often appropriate to select endpoints to be measured following selection of organisms of concern.

The endpoint ranking tables are designed to be used in conjunction with the endpoint selection guidelines. They provide an ordering of selected endpoints based on their predictive strengths, information content, and overall sensitivity. The rankings have been determined subjectively, to some extent, using available data, and are thus meant only as a form of guidance, <u>not</u> as absolute measures. It is the responsibility of the assessor to consider site-specific factors in ranking endpoints.

Within the context of the guidelines described, an investigator must exercise a considerable amount of judgment in choosing measurements appropriate to his or her unique situation. At the current time, the state-of-the-science does not include enough of a research base to provide any more specific guidance. Eventually, an expanded ecotoxicological research base should make it possible to create endpoint selection guidelines which eliminate more of the subjectivity in the selection process.

ENDPOINT SELECTION CHART

PART I - ENDPOINTS OF CONCERN

1. Is the pollutant degraded or transformed into other toxic compounds in this system?

Yes	No
Determine the basic physical and chemical properties of the pollutant and its toxic products.	Avoid selection of ecosystem or species-level endpoints that would be masked by high levels of toxicity.

2. Has the pollutant been present in the system over a long period of time?

Yes, the pollutant has been persistent or chronically released into the system over a long period of time.	No, the pollutant has been recently introduced or will be eliminated from the system in a relatively short period of time.
Select ecosystem, community, and species-level endpoints that are sensitive to long-term or short-term effects.	Select endpoints that are sensitive to short-term effects but have long-term predictive value.

3. Has the system been exposed to small amounts of the pollutant or pollutants with low levels of toxicity?

Yes

Select ecosystem, community, and species-level endpoints sensitive to low levels of toxicity.

No

4. Is the distribution of the pollutant focused in specific zones of the habitat

Yes, the chemical is concentrated in specific zones of the habitat (i.e., pond sediments, tree canopy, soil, etc.).

Focus studies primarily on polluted zones of the habitat.

No, the chemical seems to be ubiquitous in the habitat.

Focus studies on a variety of representative zones or use other factors to choose ecosystem zones.

5. Are certain processes particularly vulnerable to damage in this system?

Yes

Focus on sensitive ecosystem processes.

No

Use other factors to choose ecosystem processes to measure.

6. Are the mechanisms of toxicity known for the pollutant?

Yes, the mechanisms of toxicity are known (suppression of cell growth, inhibition of enzymes, etc.).

Use this knowledge to predict or corroborate expected toxic effects of the chemical (see step 7).

No

7. Are the generalized toxic effects of the pollutant known?

Yes	No
Yes, the toxic effects have been identified (neurotoxicity, inhibition of photosynthesis, inhibition of nitrification, etc.).	No
Focus on ecosystem and species-level endpoints associated with identified effects.	Use other factors to select ecosystem and species-level endpoints.

8. Is the pollutant known to bioaccumulate?

Yes	No
Yes, the chemicals bioaccumulate (in leaves, liver, bone, lipids, etc.).	No, the chemical is rapidly degraded or eliminated from exposed organisms.
Focus on endpoints associated with bioaccumulation.	

PART II - ORGANISMS OF CONCERN

9. Can organisms be identified which come into contact with polluted zones of the habitat?

Yes	No
Yes, the organisms which nest, feed, or otherwise pass through the polluted zones can be identified.	No
Focus on species and community level endpoints for guilds of organisms associated with these parts of the habitat.	Use other factors to select organisms to be monitored.

ENDPOINT SELECTION CHART (cont.)

10. Can highly exposed organisms be identified in the ecosystem?

Yes	No
Yes, some organisms have experienced large amounts of exposure due to migration patterns, feeding behavior, biomagnification, etc.	No
Focus on highly exposed species.	Use other factors to select organisms to be monitored.

11. Can organisms which are particularly vulnerable to the effects of this pollutant be identified?

Yes	No
Yes, this pollutant affects photosynthesis, insect development, olfactory perception etc, and thus selectively impacts upon certain groups of organisms.	No
Focus on vulnerable organisms.	Use other factors to select organisms to be monitored.

12. Can secondarily impacted organisms be identified?

Yes	No
Yes, certain organisms may be secondarily impacted through effects on their predators, prey, competitors, etc.	No
Focus on community-level endpoints involving impacted organisms.	Focus on more general measures of ecosystem structure.

13. Can impacted organisms which are particularly vulnerable to stress be identified?

Yes	No
Yes, organisms which are particularly vulnerable to stress due to reproductive cycles, population levels, disease etc. can be identified.	No
Focus on vulnerable impacted organisms.	Use other factors to select organisms to be monitored.

ENDPOINT SELECTION CHART (cont.)

14. Can indicator, keystone, or dominant species be identified?

Yes	No
Include studies of these ecologically significant species.	Use other factors to select organisms to be monitored.

ENDPOINT SELECTION GUIDELINES

PART I - ENDPOINTS OF CONCERN

1. Is the pollutant degraded or transformed into other toxic compounds in this system?

Any evaluation of the toxic effects of a pollutant on an ecosystem must include an assessment of pollutant transformation and degradation. These processes can potentially convert pollutants into compounds of equal or greater toxicity. The fungicide thiram, for example, may, be environmentally transformed or metabolized to yield carcinogenic nitrosamines (Ayanaba et al., 1973). Thus, ecosystem-level effects of derived toxic products must be characterized and evaluated along with the original pollutant.

The tendency for a pollutant to be degraded or transformed is related to its physical, chemical, and biological properties and the character of the receiving environment. Some properties of concern include molecular weight, water solubility, and partitioning behavior. Knowledge of these properties can be used to determine the susceptibility of a chemical to processes such as oxidation, microbial degradation, hydrolysis, and photolysis (Mitchell and Roberts, 1984) (see Table 1 for a detailed listing of properties and processes). Degradative and transformation processes will only proceed under appropriate environmental conditions. Factors such as the pH, temperature, and nature of the microbial populations, (See Table 1) can all effect the amount of degradation or transformation that will take place. The rate of organophosphorus and carbamate insecticide hydrolysis, for example, will depend heavily on the pH and temperature of the environment. In soil, the breakdown of these insecticides is further influenced by mineral components, organic matter, and moisture level of the soil (Murphy, 1986). It is thus necessary to characterize both the pollutant and the affected environment in order to properly evaluate the tendency for the pollutant to decompose or transform.

TABLE 1

FACTORS AFFECTING CHEMICAL DEGRADATION AND TRANSFORMATION

Chemical Properties

Chemical Stability

Lipid Solubility

Molecular Weight

Partitioning Behavior:

- Organic Carbon Soil Sorption Coefficient (Kd)
- Soil Sorption Constant (Koc)
- Water-Air Ratio (Kw)
- n-Octanol-Water Coefficient (Kow)
- Bioconcentration Factor (BCF)

pKa

Vapor Pressure

Water Solubility

Major Degradation and Transformation Processes

Hydrolysis

Microbial Processes:

- Conjugation
- Dehalogenation
- Dimerization
- Hydrolysis
- Methylation
- Oligomerization
- Oxidation
- Polymerization

Oxidation

Photolysis

Reduction

(Menzer and Nelson, 1986; NCR, 1981)

Environmental Conditions

Microbial Ecology:

- Redox Potential
- Nutrient Availability
- Microbial Interactions
- Microbial Growth
- Moisture Content of Soil

Nature of Microbial Population

pH

Presence of Clay Surfaces

Presence of Metal Ions and Metal Oxides

Presence of Organic Compounds and Organic Surfaces

Presence of Other Interactive Chemicals

Sorption to Environmental Surfaces

Temperature

2. <u>Has the pollutant been present in the system over a long period of time?</u>

If a pollutant has been present in a system for a long period of time, due either to its persistence or its chronic introduction into the system, toxic effects may be evident in measures of long-term change (see Tables A-XV and A-XVI). In this situation, ecosystem-level endpoints such as species richness and long-term changes in productivity, community-level endpoints such as shifts in trophic structure, and species-level endpoints such as growth, reproduction, and genetic changes, will provide highly informative endpoints.

Although certain measures are clearly associated with long-term stress, any endpoint can undergo changes following long-term exposure. In instances, however, when systems or species acclimate to pollutant stress, certain measures will be particularly uninformative. For example, endpoints such as diversity, productivity, or biomass often remain unchanged in systems where replacement species have caused major shifts in similarity or trophic structure. Thus lack of change in these measures can only be interpreted in conjunction with assessment of changes that have occurred in others. Choices of appropriate combinations of endpoints at the ecosystem, community, and species level, should be made to ensure that long-term effects are properly accounted for.

When a system's exposure to a toxicant is acute and the chemical is not persistant, short-term measures of changes in behavior, physiology, diversity, or productivity can serve as useful descriptions of the status of the system. Even with acute exposures, however, short-term measures may not be sufficient to evaluate ecosystem stress. In some instances short-term changes will create long-term changes in the system. For example, short-term reproductive changes in a highly vulnerable species may result in elimination of that species from the system which, in turn, could have far reaching effects on predators and prey. In addition, certain toxicants can produce long-term changes in a system or organism after only brief exposure. Thus organisms which have been briefly exposed to certain carcinogens may develop cancer a number of years later. Similarly, a brief exposure to a genotoxic chemical can induce permanent changes in the gene pool of an exposed population.

It thus seems clear that whenever long-term effects can be predicted for a system, long-term and short-term measures will need to be used in a risk assessment. If, however, it can be determined that an acute exposure will produce only acute effects, then short-term measures will provide an adequate evaluation of the ecosystem.

3. Has the system been exposed to small amounts of the pollutant or to a pollutant with low levels of toxicity?

When small amounts of a pollutant or pollutants with low levels of toxicity enter a system, the effects produced may be subtle and difficult to measure. Certain ecosystem and species-level endpoints such as nutrient cycling, behavior changes, and biochemical changes, moreover, are often highly sensitive to low levels of pollutants (See Tables A-XVII - A-XX). These endpoints will show measureable effects before any changes can be detected in other components of the system. An increased leaching of nutrients from the soil can be detected, for example, at low levels of exposure, before its cumulative effects cause a reduction in primary productivity.

When moderate or large amounts of a toxic pollutant enter a system, on the other hand, any of a large number of endpoints will serve as sensitive measures of pollutant stress. At high levels of exposure, however, species mortalities will sometimes mask effects in species-level endpoints such as behavior, reproduction, growth, or genetic shifts. Thus, ecosystem effects at high pollutant levels are sometimes assessed most effectively by focusing primarily on community-level and ecosystem-level endpoints, along with mortality.

A large variety of endpoints can be monitored if a pollutant is dispersed along a gradient. In this situation, endpoints sensitive to low levels of exposure and endpoints sensitive to high levels of exposure can be combined to provide a description of the dose-response effects for the pollutant.

4. Is the distribution of the pollutant focused in specific zones of the habitat?

Habitats are comprised of vertical and horizontal zones (see Table 2), which differ in both their biotic and abiotic components. The distribution of a pollutant across these zones is clearly an important factor in determining both the kinds of organisms and the kinds of processes that will be affected. A pollutant that is absorbed into soil, for example, will tend to affect soil microorganisms, soil invertebrates and decomposition, while a pollutant that is sequestered in the leaves of trees, might manifest its toxic effects as a reduction in primary productivity and damage to tree-dwelling organisms. Endpoint selection must thus take pollutant distribution into account.

The ultimate distribution of a pollutant is determined by a wide variety of factors. Initial deposition of the chemical will be determined by the geology, topography, and weather patterns of the ecosystem, as well as the mechanism of pollutant exposure. In a densely foliated forest, a pollutant which is dispersed atmospherically will be deposited primarily on the canopy foliage. In an area that is sparsely foliated, on the other hand, much of the pollutant will be deposited on the forest floor.

Following initial deposition, the pollutant may be secondarily deposited in different parts of the habitat. The pattern of a secondary deposition depends on both the nature of the chemical and the nature of the ecosystem. A chemical deposited on vegetation may be adsorbed, absorbed, or translocated by the plants; washed off the foliage onto nonvegetative surface; or volatilized back into the atmosphere. Likewise, a chemical deposited in water may be absorbed by biota, adsorbed onto abiotic surfaces, degraded, transported, or volatilized.

Both primary and secondary deposition sites are likely to be the most highly impacted parts of the ecosystem. Endpoints selected should thus be primarily those that would reflect toxic effects in these parts of the habitat.

TABLE 2

HABITAT - ZONES

FOREST

Canopy - Upper level of leafy branches of trees.

Understory - Lower level, shrubs, young trees, etc.

Topsoil - Decomposing litter nutrient-rich humus, and nutrient-poor mineral layer.

Subsoil - Accumulated silicates, clays, iron, aluminum, and organic matter.

Parent material - Unconsolidated weathered rock.

GRASSLAND

Vegetation - Grasses and herbs.

Topsoil - Organic matter mixed with mineral soil.

Subsoil - Calcified soil.

Parent material - Dry subsoil.

DESERT

Vegetation - Scattered xerophytes

Topsoil - Thin band, low organic matter, high nutrient content prevelent in valley floors.

Desert pavement - Stony poorly developed soil, prevalent on slopes.

TABLE 2 (CONT.)

PONDS AND LAKES

Littoral zone - Shallow marginal region with rooted vegetation.

Euphotic zone - Open water extending to the depth of light penetration.

Aphotic or Profoundal zone - Area beneath zones of photosynthesis.

Sediment - Detrital bottom layer with active decomposer communities.

STREAMS

Upper waters:

- Rapids - Regions with flow rates above 50 cm/sec.
- Pools - Regions with flow rates below 50 cm/sec.

Stream beds:

- Rocky surfaces - Firm, rocky bed beneath rapids. Soft stream bed - sandy or silty bed beneath pools.

WETLANDS

Estuarine Wetlands - Coastal wetlands associated with estuaries or brackish tidal waters.

- Regularly flooded zone.
- Irregularly flood zone.

Palustrine Wetlands - Interior wetlands generally freshwater, may be emergent, scrub-shrub or forested.

- Permanently flooded.
- Semipermanently flooded.
- Seasonally flooded.
- Temporarily flooded.

TABLE 2 (CONT.)

<u>ESTUARIES</u>

Open water - salinity gradients in large estuaries.

Mouth - Area of relatively high salinity large species numbers.

Region of Critical Salinity - Salinity range of 5%-8% low species numbers.

Region of fresh water - Species richness increases.

(Owen, 1980; McNaughton and Wolf, 1973; Levinton, 1982; Tiner, 1984)

5. <u>Are certain processes particularly vulnerable to damage in this system?</u>

It is often possible to identify ecosystem processes within a particular system which, if damaged, would seriously affect the system (see Table 3). These processes can serve as important indicators of pollutant effects and thus help the investigator focus on useful ecosystem-level endpoints to measure, and specific species to monitor.

The importance of specific processes in ecosystem stability is evidenced in a mature forest system. During the late stages of succession, nutrient cycling becomes well developed and a forest becomes highly nutrient conservative. Late successional plants are correspondingly poorly adapted to conditions of nutrient flux. Thus, in this system, measures of nutrient leaching provide highly sensitive indicators of ecosystem stress (Sheehan, 1986).

When limiting factors such as sunlight, oxygen, or specific nutrients can be identified, these also provide an important focus for determining endpoints to monitor. For example, if phosphorus is the limiting element in an aquatic system, phosphorus cycling would serve as a critical endpoint to be measured. Similarly, in the summer, the profundal zone of a eutrophic lake is subject to depleted oxygen levels. Most organisms living in this region of the lake are particularly vulnerable to pollutants which further reduce oxygen levels. Thus, mortality in the profundal zone would provide a particularly sensitive endpoint for monitoring the effects of organic wastes with a high biological oxygen demand (Owen, 1975).

6. <u>Are the mechanisms of toxicity known for the pollutant?</u>

When the biochemical mechanisms of toxicity are known for a pollutant or a closely related compound, this information will clearly narrow the endpoint selection process. Information on mechanisms is a critical factor in predicting generalized toxic effects which are themselves measureable endpoints. Such information is particularly useful in helping to select species-level endpoints and measures of ecosystem function. For example, chemicals that inhibit acetylcholinesterase are best assessed by selecting

TABLE 3

FACTORS CAUSING INCREASED VULNERABILITY OF ECOSYSTEM PROCESSES

Productivity:

- Producers are highly vulnerable to effects of pollutant
- Producers are not readily renewable
- Producers cannot readily be replaced by other producers

Nutrient Cycling

- Specific endpoints are limited for system productivity
- System is poorly adapted to conditions of nutrient flux

Decomposition

- Decomposer organisms are highly vulnerable to effects of pollutant
- System is strongly dependent on decomposition for limiting nutrients

Metabolism

- Oxygen levels become limiting in certain parts of the habitat informative, physiological endpoints such as neurological, respiratory, and cardiovascular effects (Klaasen et al., 1986). Optimally, the physiological endpoints selected should be those that can be shown to be related to organism growth, survivorship, and reproductive capacity. Similarly, when a heavy metal such as copper is known to cause membrane damage resulting in an increased loss of dissolved organic carbon, it becomes logical to assess pollutant effects on nutrient availability (Sheehan, 1984).

7. Are the generalized toxic effects of the pollutant known?

The generalized toxic effects of a pollutant are, as previously mentioned, measureable endpoints. Pollutants that are known to cause effects such as reduction in photosynthesis, inhibition of nitrification, or neurotoxicity, provide obvious ecosystem and species-level endpoints to measure on the ecosystem or species level. When this kind of information is available, it provides a critical component of the endpoint selection process.

8. Is the pollutant known to bioaccumulate?

The tendency of some pollutants to bioaccumulate or concentrate in certain kinds of organisms and tissues is important in determining toxic effects. Bioaccumulation influences both the kinds of organisms which will be highly exposed, and the ways in which the exposure will be manifested. The extent and nature of an organism's exposure is affected by its tendency to bioaccumulate the chemical, and the kinds of tissues in which the chemical is stored.

Bioaccumulation occurs as a result of the binding and nondegradative properties of a chemical. Certain compounds are highly lipophilic or have a strong tendency to bind to specific kinds of protein. Typical tissues in which chemicals are stored include plasma, fat, kidney, liver, and bone. If the site of storage is different from the site of toxicity, the process of storage may prevent the release of large amounts of toxicant to a vulnerable site. On the other hand, any factor that would promote sudden release of the chemical from storage could lead to severe toxic effects. Thus, toxicants such as DDT, chlordane, and polychlorinated biphenyls which concentrate in body fat, could be released in large amounts during periods of reproduction, migration, or starvation. Endpoint selection for lipophilic chemicals should therefore focus on processes that would enhance the release of the toxicants from fat depots.

In situations where a toxicant is stored at its known site of action, the process of bioaccumulation is likely to produce proximal toxic effects. With these kinds of toxicants, endpoints can be selected to reflect the toxic effects. In the case of fluoride, for example, which accumulates in bone, an appropriate endpoint would be skeletal morphology. Thus knowledge of a chemical's tendency to bioaccumulate should be integrated with a knowledge of the chemical's toxic effects, in determining ecological endpoints (Klaassen et al., 1986).

PART II - ORGANISMS OF CONCERN

9. Can organisms be identified which come into contact with polluted zones of the habitat?

Once primary and secondary deposition sites have been identified for a pollutant, it becomes possible to identify organisms which come into contact with these parts of the ecosystem. Guilds or groups of organisms which nest, feed, or reproduce in polluted zones of the habitat, and organisms which pass through for other purposes may be characterized (See Table 4). It thus becomes possible, with knowledge of species' life histories, to identify the groups of organisms which are most likely to be exposed to the pollutant.

TABLE 4
BEHAVIOR CAUSING CONTACT WITH POLLUTED ZONES OF THE HABITAT

Breeding	Migrating
Burrowing	Nesting
Denning	Passing through
Drifting	Resting
Feeding	Roosting
Hibernating	Sunning

10. <u>Can highly exposed organisms be identified?</u>

Organisms that come into contact with polluted areas may be exposed to particularly large amounts of pollutants as a result of a variety of behavioral and life history factors. For example, organisms which filter feed in polluted sediment, or retain large amounts of the pollutant in their bodies, may be subject to high levels of exposure.

Organisms which do not come into direct contact with polluted areas of the ecosystem may also be indirectly exposed to large amounts of pollutant through the process of biomagnification up the food chain. These highly exposed organisms are clearly important candidates for endpoint measurements.

TABLE 5
FACTORS LEADING TO HIGH LEVELS OF EXPOSURE IN ORGANISMS

- o Biomagnification
- o Organisms retain pollutant
- o Organisms bioconcentrate pollutant
- o Organisms feed on exposed materials
- o Organisms readily absorb pollutant

11. <u>Can Organisms Which Are Particularly Vulnerable to the Effects of this Pollutant be Identified?</u>

The toxic effects of some pollutants are only manifested in certain selected types of organisms. Various categories of pesticides, for example, may produce toxic effects on specific target organisms, and little or no effects in non-target species. Thus, an herbicide which is highly toxic to weeds, may not be toxic to other autotrophs or heterotrophs. Similarly, an insecticide may have minimal direct impact on species of plants or higher vertebrates.

It thus may be possible to narrow the selection of species to be monitored based on knowledge of the toxic mechanisms of a particular pollutant. An identification of primarily impacted organisms can then facilitate the identification of secondarily impacted organisms (see Question 12).

12. Can secondarily impacted organisms be identified?

Fluctuations in populations of exposed organisms may have a secondary impact on other members of the community. Secondary impact will be particularly significant in communities where species interactions are strong (Levin et al., 1984). It is manifested through interactions such as predation, competition, and symbiosis. Elimination of exposed prey species for a highly specialized predator could be devastating to the predator population. On the other hand, elimination of an exposed organism could allow a large increase in the density of a competitor population. Secondarily impacted organisms may thus become severely stressed or increasingly dominant as a result of shifts in populations of exposed species.

Organisms which may be secondarily impacted can be identified within both exposed and unexposed communities based on knowledge of the community structure. This knowledge can help direct the selection of population-level endpoints.

TABLE 6

SECONDARILY EXPOSED ORGANISMS

- Competitors with exposed species
- Competitors with prey of exposed species
- Herbivores feeding on exposed plants
- Organisms that obtain shelter in or on exposed plants
- Predators on exposed species
- Symbiotes of exposed species

13. Can organisms which are particularly vulnerable to stress be identified?

When large numbers of impacted organisms have been identified, it becomes useful to be able to focus on those species which are most likely to manifest effects of exposure. In the population of exposed and secondarily impacted species some may be identifiable as being particularly vulnerable at the time of exposure. Examples of vulnerable species which can be identified include those with large numbers of larval or newly emergent individuals, k-selected species with a relatively long reproductive lag time, and previously stressed species which already have low population densities (see Table 7).

In addition to organisms which exhibit system-specific vulnerability, accounting must be taken of endangered species which possess a global vulnerability. Although an endangered population may not be highly sensitive to a particular pollutant in a particular system, exposure effects that produce even a small impact on the endangered population could have broad-ranging implications for the species as a whole. It thus becomes important to include an evaluation of any endangered species as a component of a risk assessment.

TABLE 7

POTENTIALLY VULNERABLE ORGANISMS

- Endangered species
- Larva or newly emergent individuals
- Overwintering organisms*
- Populations with very low densities
- Populations at the carrying capacity of the environment
- Species with a relatively long reproductive lag time

*These species would be more vulnerable due to lack of avoidance behavior and slowed metabolic detoxification and elimination of chemicals. They may, however, be less vulnerable, due to slowed transformation of chemicals to more toxic substances.

14. Can indicator, dominant, or keystone species be identified?

When indicator, dominant, or keystone species can be identified in an ecosystem, they often provide sensitive indicators of ecosystem stress. Indicator species are designated as organisms whose absence from an environment suggests a lack of suitable environmental conditions. Although only limited work has been done in this area, when indicator organisms can be identified in a particular system, they provide an obvious focus for endpoint investigations. Lichens, for example, have been found to be effective monitors of SO_2 stress in a number of different studies (Sheehan, 1986). Other species may ultimately be identified to serve as standard indicators for certain kinds of pollutants or habitats.

II. ENDPOINT RANKING

Endpoint rankings provide a means of comparing endpoints based on their overall predictive value. They can thus serve as a useful tool to aid in choosing from among previously selected, situationally appropriate endpoints.

The tables that follow present a sample endpoint ranking scheme. Within this scheme, endpoints have been evaluated for their information content, sensitivity to low pollutant levels, predictive values for assessing ecosystem stress and long-term effects, and practicality. The rankings obtained are summarized in Tables I-VI. These are followed by detail tables which describe the basis for each ranking.

None of the rankings provided here are meant to be absolute. The endpoints listed include general categories of measurement. Within these categories individual measures may prove to be more or less sensitive. In addition, ranking decisions are, to some extent subjective, and are often based on a fairly limited database. These rankings should therefore serve as a model, which should be modified as necessary in accordance with the needs of the investigator.

Description of Ranking Factors

Five factors were chosen as components of ranking. These factors include:

- Information Content - The extent to which the endpoint describes the status of the whole ecosystem
- Predictive of Ecosystem Stress - The value of the endpoint in predicting damage to the ecosystem
- Predictive of Species Stress - The value of the endpoint in predicting damage to the species
- Predictive of Long-Term Effects - The value of the endpoint in predicting long-term damage to the species or the system
- Sensitive to Low Pollutant Levels - Tendency of endpoint to change in response to small amounts of exposure
- Practicality - A combination of cost and ease of measurement.

Using these factors as criteria, endpoints were than rated on a 3-point scale, with a score of 3 being given to the most predictive, practical, or informative endpoints. A final rank order was determined by adding up the endpoint scores for all the factors except practicality. A second rank order was also determined with practicality included. The final ranking tables provide a rough order of prioritization for selected ecosystem, population, and species-level endpoints. It is recognized that other ranking systems are possible. However, the approach selected here provides a useful basis for decision-making and for data collection.

ENDPOINT RANKING TABLES

TABLE A-I

ENDPOINT RANKING SUMMARY*

ECOSYSTEM POPULATION LEVEL		SPECIES LEVEL	
Nutrient Cycles	12	Growth	12
Decomposition	11	Reproduction	12
Similarity	11	Developmental	11
Trophic Structure	11	Acute Mortality	11
Keystone Species	10	Carcinogenic	10
		Physiology	10
Primary Production	10		
Species Richness	9.5		
Metabolism	9	Genetics/ (hereditable)	10
Predator-Prey	9		
Indicator Species	8		7
		Year-class distribution	10
Competition	8		
Biological Indices	6.5		
Biomass	6.5	Morphology	9
Behavior	9	Behavior	9
Diversity	6.5	Biochemical	8
Abundance	5.5		

* Excluding practicality, but including factors described on pgs. 27-31.

TABLE A-II

ENDPOINT RANKING INCLUDING PRACTICALITY*

ECOSYSTEM/POPULATION LEVEL		SPECIES LEVEL	
Nutrient Cycles	14	Growth	14
Decomposition	13	Reproduction	14
Primary Production	12.5	Acute Mortality	14
Similarity	12.5	Developmental Changes	13
Keystone Species	12	Carcinogenic	12
Trophic Structure	12	Physiological	12
Species Richness	11.5	Morphology	12
Metabolism	10.5	Year-Class Distribution	12
Indicator Species	10	Biochemical	11
Predator-Prey	10	Genetics/(hereditable)	11
Biomass	9.5	Behavior	10.5
Abundance	8.5		
Biologic Indices	8.5		
Diversity	8.5		
Competition	8		

* See discussion of factors on pgs. 27-31.

TABLE A-III

ECOSYSTEM/POPULATION
ENDPOINT RANKING

ECOSYSTEM/ POPULATION-LEVEL ENDPOINTS	INFORMATION CONTENT	PREDICTIVE OF ECOSYSTEM STRESS	PREDICTIVE OF LONG-TERM EFFECTS	SENSITIVE TO LOW POLLUTANT LEVELS	TOTAL SCORE
Abundance	1	1.5	1	2	5.5
Biological Indexes	1.5	2	1	2	6.5
Biomass	1	1.5	2	2	6.5
Competition	2	2	2	2	8
Decomposition	3	3	3	2	11
Diversity	1.5	2	2	1	6.5
Indicator Species	2	2	2	2	8
Keystone Species	3	2	3	2	10
Metabolism	2	3	1	3	9
Nutrient Cycles	3	3	3	3	12
Predator-Prey	2	2	2	3	9
Primary Production	3	3	2	2	10
Species Richness	2	2.5	2	3	9.5
Similarity	3	3	2	3	11
Trophic Structure	3	3	3	2	11

Key: 1 - Minimally informative/predictive/sensitive
2 - Informative/predictive/sensitive
3 - Highly informative/predictive/sensitive

TABLE A-IV

ECOSYSTEM/POPULATION ENDPOINT
RANKING WITH PRACTICALITY

ECOSYSTEM/ POPULATION- LEVEL ENDPOINTS	INFORMA- TION CONTENT	PREDICTIVE OF ECOSYSTEM STRESS	PREDICTIVE OF LONG-TERM EFFECTS	SENSITIVE TO LOW POLLUTANT LEVELS	PRACTI- CALITY	TOTAL SCORE
Abundance	1	1.5	1	2	3	8.5
Biological Indexes	1.5	2	1	2	2	8.5
Biomass	1	1.5	2	2	3	9.5
Competition	2	2	1	2	1	8
Decomposition	3	3	3	2	2	13
Diversity	1.5	2	2	1	2	8.5
Indicator Species	2	2	2	2	2	10
Keystone Species	3	2	3	2	2	12
Metabolism	2	3	1	3	1.5	10.5
Nutrient Cycles	3	3	3	3	2	14
Predator-Prey	2	2	1	3	2	10
Primary Production	3	3	2	2	2.5	12.5
Species Richness	2	2.5	2	3	2	11.5
Similarity	3	3	2	3	1.5	12.5
Trophic Structure	3	3	3	2	1	12

Key: 1 - Minimally informative/predictive/sensitive
2 - Informative/predictive/sensitive
3 - Highly informative/predictive/sensitive

TABLE A-V

SPECIES ENDPOINT RANKING

SPECIES-LEVEL ENDPOINTS	INFORMATION CONTENT	PREDICTIVE OF SPECIES STRESS	PREDICTIVE OF LONG-TERM EFFECTS	SENSITIVE TO LOW POLLUTANT LEVELS	TOTAL SCORE
Acute Mortality	3	3	3	2	11
Behavior	2	2	2	3	9
Biochemical	3	1	1	3	8
Carcinogenic	2	3	3	2	10
Developmental	3	2	3	3	11
Genetics/ (hereditable)	2	3	3	2	10
Growth	3	3	3	3	12
Morphology	2	2	3	2	9
Physiology	3	2	2	3	10
Reproduction	3	3	3	3	12
Year-Class Distribution	2	2	3	3	10

Key: 1 - Minimally informative/predictive/sensitive
2 - Informative/predictive/sensitive
3 - Highly informative/predictive/sensitive

TABLE A-VI

SPECIES ENDPOINT RANKING
INCLUDING PRACTICALITY

SPECIES-LEVEL ENDPOINTS	INFORMA-TION CONTENT	PREDICTIVE OF SPECIES STRESS	PREDICTIVE OF LONG-TERM EFFECTS	SENSITIVE TO LOW POLLUTANT LEVELS	PRACTIC-ABILITY	TO SC
Acute Mortality	3	3	3	2	3	
Behavior	2	2	2	3	1.5	
Biochemical	3	1	1	3	3	
Carcinogenic	2	3	3	2	2	
Developmental	3	2	3	3	2	
Genetics/ (hereditable)	2	3	3	2	1	
Growth	3	3	3	3	2	
Morphology	2	2	3	2	3	
Physiology	3	2	2	3	2	
Reproduction	3	3	3	3	2	
Year-Class Distribution	2	2	3	3	2	

Key: 1 - Minimally informative/predictive/sensitive
2 - Informative/predictive/sensitive
3 - Highly informative/predictive/sensitive

TABLE A-VII

ECOSYSTEM/POPULATION ENDPOINT INFORMATION CONTENT SUMMARY

RANKING	INFORMATION CONTENT
High - 3 -	DECOMPOSITION KEYSTONE SPECIES NUTRIENT CYCLES SIMILARITY TROPHIC STRUCTURE
Medium - 2 -	Competition Indicator Species Metabolism Predator-Prey Species-Richness
Low - 1 -	Abundance Biologic Indices Biomass Diversity

TABLE A-VIII

INFORMATION CONTENT - ECOSYSTEM/POPULATION-LEVEL ENDPOINTS

ECOSYSTEM/ POPULATION-LEVEL END-POINTS	INFORMATIVE	COMMENTS
ABUNDANCE	1	The absolute numbers of living organisms in an ecosystem. An aspect of ecosystem structure. Not very informative. Best when used with other measures.
BIOLOGIC INDEXES	1.5*	Numerical rating of species and species assemblages. Integrates measures of species abundance and pollution tolerance. Information value not clear. Many indexes require subjective determinations of organism tolerance. In addition scores do not distinguish different combinations of evaluated factors.
BIOMASS	1	The total weight of organisms in an ecosystem. Not very informative. A gross measure of ecosystem structure. Best when used with other measures.
COMPETITION	2*	Exclusion of one species in favor of a competitor. Provides information on community structure. Potentially informative but difficult to measure.
DECOMPOSITION	3	Measures of litter decomposition and decomposer organisms. Serves as a major link between nutrient availability and primary production. Informative about potential shifts in other aspects of ecosystem function.
DIVERSITY	1.5	Combines measures of species richness and equitability. Measured using a variety of indices. There is no clear theoretical basis for application of these indices. Most indices are, further, insensitive to changes in community structure.

Key: 1 - Provides minimal information
2 - Informative
3 - Highly informative
* - Not well studied with toxic chemicals
++ - Highly informative in selected situations

INFORMATION CONTENT (cont.)

ECOSYSTEM/ POPULATION-LEVEL END-POINTS	INFORMATIVE	COMMENTS
INDICATOR SPECIES	2	The presence of one or more species serves as an indication of acceptable environmental conditions. Can be informative when used with knowledge of the system.
KEYSTONE SPECIES	3++	Key predators whose elimination can lead to major changes in the ecosystem. Can be very informative when used with knowledge of the system.
METABOLISM P/R	2	The photosynthesis/respiration ratio provides an integrative measure of ecosystem metabolism. Particularly predictive in a mature successional system.
NUTRIENT CYCLES	3	Measures of nutrient concentrations in soil and living organisms, and levels of nutrient leaching in soil. Informative about functional status of ecosystem. Sensitive to low levels of pollutant stress. Thus, provides early warning of pollutant damage.
PREDATOR-PREY	2	Predator-prey measures include changes in prey escape, antipredator behavior, and shifts in predator and prey populations. Provides information concerning effects on species and community structure. May be informative about system if species are keystone, indicator, or dominant.

Key: 1 - Provides minimal information
2 - Informative
3 - Highly informative
* - Not well studied with toxic chemicals
++ - Highly informative in selected situations

ECOSYSTEM/ POPULATION LEVEL END-POINTS	INFORMATIVE	COMMENTS
PRIMARY PRODUCTION	3	Measures of gross or net autotroph productivity through monitoring of O_2, CO_2, chlorophyll, or biomass. Determines the amount of living tissue that an ecosystem can support. Thus, provides critical information about status of system.
SPECIES RICHNESS	2	The number of species per unit area or per fixed number of individuals. Provides limited information on community structure. Suggestive of whole system stress. Best when used with other measures.
SIMILARITY	3	A comparative measure of species presence or proportional abundance over time and space. Provides important information concerning changes in community structure.
TROPHIC STRUCTURE	3	Changes in the composition of different trophic levels can be made using measures such as biomass, richness, productivity etc. Such measures made at several levels are highly informative about community structure.

Key: 1 - Provides minimal information
2 - Informative
3 - Highly informative
* - Not well studied with toxic chemicals
++ - Highly informative in selected situations

TABLE A-IX

SPECIES-LEVEL
INFORMATION CONTENT SUMMARY

RANKING	INFORMATION CONTENT
High - 3 -	ACUTE MORTALITY BIOCHEMICAL CHANGES DEVELOPMENTAL CHANGES GROWTH PHYSIOLOGICAL EFFECTS REPRODUCTIVE EFFECTS
Medium - 2 -	Behavioral Changes Carcinogenic Effects Genetic Changes Morphological Effects Year-Class Distribution
Low - 1	

TABLE A-X

INFORMATION CONTENT - SPECIES-LEVEL ENDPOINTS

SPECIES-LEVEL ENDPOINTS	INFORMATIVE	COMMENTS
ACUTE MORTALITY	3	Direct counts of dead organisms. This is a gross measure. Laboratory tests can provide information concerning dose-response levels. Not informative about mechanisms of toxicity. May be informative about effects on system particularly if indicator or keystone species is monitored. The relationship between acute mortality and success is well established.
BEHAVIORAL CHANGES	2	Avoidance, locomotion, feeding, escape etc. Information gained depends on the behavior monitored. Can provide information on the mechanism of toxicity. Not highly informative about the extent of ecosystem stress.
BIOCHEMICAL CHANGES	3	Changes in levels of enzymes and hormones, or chromosomal damage. Very informative about the mechanism of toxicity. Minimal predictive value about species or ecosystem stress.
CARCINOGENIC EFFECTS	2	Counts of tumor incidence and precarcinogenic tissue changes. The lack of data on normal tumor incidence and the complex etiology of different forms of cancer makes data difficult to interpret.
DEVELOPMENTAL CHANGES	3	Fertilization of egg through maturity. Informative about effects on species and mechanism of toxicity.
GENETIC CHANGES (HEREDITABLE)	2	Permanent change in the genotype of the species. This represents a long-term adaptive change in the species. Very informative about species effects.

Key: 1 - Provides minimal information
2 - Informative
3 - Highly informative

INFORMATION CONTENT (cont.)

SPECIES-LEVEL ENDPOINTS	INFORMATIVE	COMMENTS
GROWTH	3	Integrated index of physiological status. Net result of consumption, excretion, and respiration. Informative concerning effects of pollutant on species.
MORPHOLOGICAL EFFECTS	2	Cell and tissue changes and gross deformities. May be informative concerning species stress and the mechanism of toxicity.
PHYSIOLOGICAL EFFECTS	3	Feeding activity, metabolism, osmotic-ionic balance and photosynthetic activity. Highly informative about species stress. Also informative concerning mechanisms of toxicity.
REPRODUCTIVE EFFECTS	3	Courtship, mating, fertilization, and reproductive success. Highly informative about species stress. Also informative concerning mechanisms of toxicity.
YEAR-CLASS DISTRIBUTION	2	The distribution of the different life stages of a particular species. Provides information about stress to overall species effects. A particular life stage, but it is difficult to extrapolate.

Key: 1 - Provides minimal information
2 - Informative
3 - Highly informative

TABLE A-XI

ECOSYSTEM/POPULATION-LEVEL
PREDICTIVE OF STRESS - SUMMARY

RANKING	PREDICTIVE OF ECOSYSTEM POPULATION-LEVEL STRESS
High - 3 -	DECOMPOSITION
	METABOLISM
	NUTRIENT CYCLES
	PRIMARY PRODUCTION
	SIMILARITY
	TROPHIC STRUCTURE
Medium - 2 -	Biologic Indices
	Competition
	Diversity
	Indicator Species
	Keystone Species
	Predator-Prey
	Species Richness
Low - 1 -	Abundance
	Biomass

TABLE A-XII

ECOSYSTEM STRESS - ECOSYSTEM/POPULATION-LEVEL ENDPOINTS

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE ECOSYSTEM STRESS	COMMENTS
ABUNDANCE	1.5	Changes in abundance are suggestive of ecosystem stress, but do not provide enough information to be used alone as indicators.
BIOLOGIC INDEXES	2*	Designed primarily as a method of evaluating effects of municipal sewage or organic wastes on aquatic systems. Can be predictive, but usefulness with toxic chemicals not well tested.
BIOMASS	1.5	Changes in biomass are suggestive of ecosystem stress but do not provide enough information to be used alone as indicators. Autotroph biomass is also used as a measure of primary productivity. Can be useful when measured as a change in biomass.
COMPETITION	2	May not be highly predictive between the laboratory and the field. Could be predictive if measured in the field.
DECOMPOSITION	3	As an important functional process in an ecosystem, damage to process of decomposition can have effects on both nutrient availability and primary productivity. Thus it is highly predictive of stress on whole systems.
DIVERSITY	2	Good indicator of gross environmental deterioration. Useful at high levels of pollutant stress. Not effective with all pollutants and often a poor measure at low pollutant levels.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive
* - Not well tested
++ - Can be highly predictive in appropriate systems

ECOSYSTEM STRESS (cont.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE ECOSYSTEM STRESS	COMMENTS
INDICATOR SPECIES	2	Can be very useful when appropriate species can be identified and their life histories are well understood. Choice of indicator species is based, however, on a subjective determination of species tolerance.
KEYSTONE SPECIES	2++	When keystone species can be identified damage to the species will be highly predictive of ecosystem stress.
METABOLISM P/R	3	Can serve as a sensitive indicator of ecosystem stress. However, this measure can be deceptive in situations where a toxic chemical reduces both primary production and respiration.
NUTRIENT CYCLES	3	Highly sensitive to low levels of pollutant stress. Because impacts of nutrient shifts are ultimately manifested in changes in productivity, this endpoint serves as an important measure of ecosystem stress.
PREDATOR-PREY	2	May have predictive power between laboratory and field. Could be predictive if measured in the field.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive
* - Not well tested
++ - Can be highly predictive in appropriate systems

ECOSYSTEM STRESS (cont.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE ECOSYSTEM STRESS	COMMENTS
PRIMARY PRODUCTION	3	Changes in productivity are indicative of changes in the energy base of the system. Short-term changes, however, may not be predictive in situations where replacement species can take over productive functions. Highly predictive long-term measure.
SPECIES RICHNESS	2.5	Generally a good predicator of ecosystem stress with richness decreasing in the presence of pollutants.
SIMILARITY	3	When comparative or gradient information is available, similarity indices provide a highly sensitive measure of ecosystem stress. Studies show sensitivity at low levels of pollutant input.
TROPHIC STRUCTURE	3	This involves multiple measures of selected endpoints at different trophic levels. Shifts in trophic dominance can have serious implications for the state of the ecosystem.
SPECIES-LEVEL ENDPOINTS GENERAL	2	May be predictive if effects are monitored for indicator, keystone, or dominant species. Serious effects on critical species are indicative of serious effects on the system.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive

TABLE A-XIII

SPECIES-LEVEL
PREDICTIVE OF SPECIES STRESS - SUMMARY

RANKING	PREDICTIVE OF SPECIES STRESS
High - 3 -	ACUTE MORTALITY
	CARCINOGENIC EFFECTS
	GENETIC CHANGES
	GROWTH
	REPRODUCTIVE CHANGES
Medium - 2 -	Behavioral Effects
	Developmental Changes
	Morphological Effects
	Physiological Effects
	Year-Class Distribution
Low - 1 -	Biochemical Changes

TABLE A-XIV

SPECIES STRESS - SPECIES-LEVEL ENDPOINTS

SPECIES-LEVEL ENDPOINTS	PREDICTIVE SPECIES STRESS	COMMENTS
ACUTE MORTALITY	3	Clearly predictive of stress to an individual species. Lab tests, however, do not always predict field mortality.
BEHAVIORAL EFFECTS	2	Behavior may be predictive of species stress, particularly changes in feeding, parental, or reproductive behaviors. Behavioral changes may be temporary, however, returning to normal over time.
BIOCHEMICAL CHANGES	1	Biochemical changes are difficult to extrapolate to the long-term well being of effected organisms.
CARCINOGENIC CHANGES	3	Clearly detrimental to effected organisms and thus predictive of stress to a species.
DEVELOPMENTAL CHANGES	2	Effect of pollutant at any stage of development can reduce the probability of the individual successfully completing its life cycle. Thus, this endpoint is predictive of species success.
GENETIC CHANGES (HEREDITABLE)	3	Represents long-term pollutant effects of species. Highly predictive of species effects.
GROWTH	3	Integrated index of physiological status of species. Good predicator of species stress.
MORPHOLOGICAL EFFECTS	2	May suggest damage to species, but the fact that the animal survives suggests that changes may not be detrimental. Suggestive if damage effects other measures as well.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive

SPECIES STRESS (cont.)

SPECIES-LEVEL ENDPOINTS	PREDICTIVE SPECIES STRESS	COMMENTS
PHYSIOLOGICAL EFFECTS	2	These changes can be seriously damaging to the species. In some instances these changes are only short-lived, thus they are most predictive with long-term monitoring.
REPRODUCTIVE CHANGES	3	A critical function essential to continuation of the species. This provides the ultimate test of the effects of sublethal concentrations of pollutants on a species.
YEAR-CLASS DISTRIBUTION	2	Particular life stages are sometimes more sensitive to toxicant stresses than others. This can have important consequences on the species, which are difficult to predict.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive

TABLE A-XV

ECOSYSTEM/POPULATION-LEVEL
LONG-TERM EFFECTS - SUMMARY

RANKING	PREDICTIVE OF LONG-TERM EFFECTS
High - 3 -	DECOMPOSITION KEYSTONE SPECIES NUTRIENT CYCLES TROPHIC STRUCTURE
Medium -2 -	Biomass Competition Diversity Indicator Species Predator-Prey Primary Production Species Richness Similarity
Low - 1 -	Abundance Biologic Indices Metabolism

TABLE A-XVI

PREDICTIVE OF LONG-TERM EFFECTS - ECOSYSTEM/POPULATION-LEVEL ENDPOINTS

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE OF LONG-TERM EFFECTS	COMMENTS
ABUNDANCE	1	Altered abundance may return to normal over time due to replacement species or species acclimation. Thus short-term changes in abundance do not predict long-term changes.
BIOLOGIC INDEXES	1*	May be predictive but this has not been well tested with toxic substances.
BIOMASS	2	Altered biomass may return to normal over time due to replacement species or species acclimation. Thus, short-term changes in biomass may not predict long-term changes. Short-term changes in autotroph biomass can lead to loss of energy base and have long term effects on higher trophic levels.
COMPETITION	2*	Affects species composition. Structural changes likely to be long lasting. Long-term effects on system may be difficult to predict based on short-term competitive interactions.
DECOMPOSITION	3	Changes in decomposer organism populations predictive of long-term changes in decomposition, primary productivity, and nutrient cycling.
DIVERSITY	2++	Can be predictive in situations where pollutant levels are high. May be predictive in other situations but more work needs to be done to show this. In stressed communities under relatively constant pollution pressure, diversity tends to be high. Thus this endpoint would not be predictive under these conditions.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive
* - Not well tested
++ - Can be highly predictive in appropriate systems

PREDICTIVE OF LONG-TERM EFFECTS (cont.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE OF LONG-TERM EFFECTS	COMMENTS
INDICATOR SPECIES	2++	If indicator species can be identified it would be suggestive of serious long-term changes in the system.
KEYSTONE SPECIES	3++	If keystone species is identified, effects on this species will, by definition, have long-term effects on the other species in the system.
METABOLISM P/R	1	Metabolism may vary over the long-term time. Predictability depends on the system.
NUTRIENT CYCLES	3	Changes in nutrient levels can result in long-term effects on productivity and thus on the energy base for the system.
PREDATOR-PREY	2	Affects species composition. Structural changes likely to be long lasting. Long-term effects on system may be difficult to predict based on short-term shifts in predator-prey interactions.
PRIMARY PRODUCTION	2++	Short-term changes be reversed by replacement species in some systems.
SPECIES RICHNESS	2	Can be predictive in systems stressed with high levels of pollutants. Effects in other systems not certain.

Key:
1 - Minimally predictive
2 - Predictive
3 - Highly predictive
* - Not well tested
++ - Can be highly predictive in appropriate systems

PREDICTIVE OF LONG-TERM EFFECTS (cont.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	PREDICTIVE OF LONG-TERM EFFECTS	COMMENTS
SIMILARITY	2	Likely to be predictive in systems stressed with high levels of pollutants, effects on other systems not certain.
TROPHIC STRUCTURE	3	Shifts in trophic structure reflect long-term effects on all components of the ecosystem.
SPECIES LEVEL ENDPOINTS GENERAL	2	May be predictive if effects are monitored for indicator, keystone, or dominant species. Serious effects on critical species will produce long-term effects on entire system.

Key: 1 - Minimally predictive
2 - Predictive
3 - Highly predictive
* - Not well tested
++ - Can be highly predictive in appropriate systems

TABLE A-XVII

SPECIES-LEVEL
PREDICTIVE OF LONG-TERM EFFECTS

RANKING	INFORMATION CONTENT
High - 3 -	ACUTE MORTALITY CARCINOGENIC EFFECTS DEVELOPMENTAL CHANGES GENETICS/HEREDITABLE GROWTH MORPHOLOGICAL EFFECTS REPRODUCTIVE EFFECTS YEAR-CLASS DISTRIBUTION
Medium - 2 -	Behavioral Changes Physiological Effects
Low - 1 -	Biochemical Changes

TABLE A-XVIII

PREDICTIVE OF LONG-TERM EFFECTS SPECIES-LEVEL ENDPOINTS

SPECIES-LEVEL ENDPOINTS	PREDICTIVE OF LONG-TERM EFFECTS	COMMENTS
ACUTE MORTALITY	3	Predictive of damage to species as a result of loss of individuals.
BEHAVIOR	3	Predictive of damage to species as a result of loss of individuals.
BIOCHEMICAL CHANGES	2	Biochemical changes are generally sensitive to short term pollutant stress. Evidence is limited on long-term predictiveness of biochemical changes.
CARCINOGENIC EFFECTS	3	Predictive of weakened individuals and thus damage to the species.
DEVELOPMENTAL	3	Predictive of long-term damage to the species.
GENETICS/ HEREDITABLE	3	These changes generally occur over long periods of time. Even rapid turn-over insect populations take 2-3 years to develop resistance. Thus, this is a long-term measure.
GROWTH	3	This is a long-term measure that is predictive of long-term stresses to the species.
MORPHOLOGICAL EFFECTS	3	Depending on the severity of morphological changes, may be predictive of weakened organisms and thus, species damage.

PREDICTIVE OF LONG-TERM EFFECTS SPECIES LEVEL ENDPOINTS (CONT.)

SPECIES-LEVEL ENDPOINTS	PREDICTIVE OF LONG-TERM EFFECTS	COMMENTS
PHYSIOLOGICAL EFFECTS	2	Depends on the physiological changes being measured. Short-term changes in respiration may vanish if species acclimates. Changes in osmoregulatory function or photosynthetic rates may, on the other hand, be predictive of long-term species damage.
REPRODUCTIVE EFFECTS	3	Diminished reproductive capacity will diminish the survival potential of the species.
YEAR-CLASS DISTRIBUTION	3	An integrative measure of long-term changes in a species. Predictive of species damage.

TABLE A-XIX

ECOSYSTEM/POPULATION-LEVEL LOW POLLUTANT LEVELS SUMMARY

RANKING	SENSITIVE TO LOW POLLUTANT LEVELS
High - 3 -	METABOLISM NUTRIENT CYCLES PREDATOR-PREY SPECIES RICHNESS SIMILARITY
Medium - 2 -	Abundance Biologic Indices Biomass Competition Decomposition Indicator Species Keystone Species Primary Production Trophic Structure
Low - 1 -	Diversity

TABLE A-XX

SENSITIVITY TO POLLUTANT LEVELS - ECOSYSTEM/POPULATION-LEVEL ENDPOINTS

ECOSYSTEM/ POPULATION LEVEL END-POINTS	SENSITIVE TO LOW LEVELS OF POLLUTANTS	COMMENTS
ABUNDANCE	2	Dependent on the nature of the pollutant and the system.
BIOLOGIC INDEXES	2	Known to be sensitive for organic wastes. Not well tested with toxicants.
BIOMASS	2	Dependent on the nature of the pollutant and the system.
COMPETITION	2*	Potentially sensitive with highly sensitive species.
DECOMPOSITION	2	Studies indicate that decomposition will be disrupted, at least at moderate to high pollutant levels.
DIVERSITY	1	Tends to be insensitive at low to moderate levels of pollution.
INDICATOR SPECIES	2	Depends on species level endpoint used.
KEYSTONE SPECIES	2	Depends on species-level endpoint used.
METABOLISM	3*	Studies indicate sensitivity.
NUTRIENT CYCLES	3	Studies show that these are highly sensitive to low levels of pollutants.
PREDATOR PREY	3	Studies suggest that this endpoint can be sensitive to low levels of pollutants.

Key: 1 - Minimal sensitivity
2 - Sensitive
3 - Highly sensitive
* - Not well studied

SENSITIVITY TO POLLUTANT LEVELS (CONT.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	SENSITIVE TO LOW LEVELS OF POLLUTANTS	COMMENTS
PRIMARY PRODUCTION	2	May be slow to manifest effects from low-levels of pollutants.
SPECIES RICHNESS	3	Sensitive at different pollutant levels. Useful for measuring gradient effects. But sensitivity may vary with system.
SIMILARITY	3	Studies show sensitivity at low pollutant levels.
TROPHIC STRUCTURE	2	Depends on endpoints measured within trophic levels.

Key: 1 - Minimal sensitivity
2 - Sensitive
3 - Highly sensitive

TABLE A-XXI

SPECIES-LEVEL RANKING
LOW POLLUTANT LEVEL SUMMARY

RANKING	SENSITIVE TO LOW POLLUTANT LEVELS
High - 3 -	BEHAVIORAL CHANGES BIOCHEMICAL CHANGES DEVELOPMENTAL CHANGES GROWTH PHYSIOLOGICAL EFFECTS REPRODUCTIVE EFFECTS YEAR-CLASS DISTRIBUTION
Medium - 2 -	Acute Mortality Carcinogenic Effects Genetic Changes Morphological Effects
Low - 1	

TABLE A-XXII

SENSITIVITY TO POLLUTANT LEVELS - SPECIES-LEVEL ENDPOINTS

SPECIES-LEVEL ENDPOINTS	SENSITIVE TO LOW LEVELS OF POLLUTANTS	COMMENTS
ACUTE MORTALITY	2+	Dependent on toxicity of pollutant and sensitivity of the species monitored.
BEHAVIORAL CHANGES	3	Behavioral responses are often sensitive to low levels of pollutants.
CARCINOGENIC CHANGES	2	Dependent on the carcinogenicity of the pollutant and sensitivity of the species monitored.
DEVELOPMENTAL CHANGES	3	Early life stages have been shown to be sensitive to low levels of pollutants. Changes in response to low levels of pollutants have also been noted in eggshells.
GENETIC CHANGES (HEREDITABLE)	2	Long-term measure. More research needed to determine effects of low pollutant levels.
MORPHOLOGICAL EFFECTS	2*	Evidence not sufficient concerning low level pollutant effects on morphological endpoints.

Key: 1 - Minimal sensitivity
2 - Sensitive
3 - Highly sensitive
* - Not well studied

+Mortality will mask other species level effects at high levels of pollutant stress.

SENSITIVITY TO POLLUTANT LEVELS (CONT.)

SPECIES LEVEL END-POINTS	SENSITIVE TO LOW LEVELS OF POLLUTANTS	COMMENTS
PHYSIOLOGICAL EFFECTS	3	Studies indicate that certain physiological endpoints such as respiration demonstrate a graded response over a range of pollutant exposures.
REPRODUCTIVE EFFECTS	3	Certain measures of reproduction can be highly sensitive to low pollutant levels. For example, certain metals are toxic to gamates of aquatic species which exhibit external fertilization.
YEAR-CLASS DISTRIBUTION	3	Early life stages have been shown to be sensitive to low levels of pollutants.

Key: 1 - Minimal sensitivity
2 - Sensitive
3 - Highly sensitive

TABLE A-XXIII

POPULATION/ECOSYSTEM-LEVEL
PRACTICALITY - SUMMARY

RANKING	PRACTICALITY
High - 3 -	ABUNDANCE BIOMASS
Medium - 2 -	Biologic Indices Decomposition Diversity Indicator Species Keystone Species Nutrient Cycles Predator-Prey Primary Production Species Richness
Low - 1 -	Competition Metabolism Trophic Structure

TABLE A-XXIV

PRACTICALITY - ECOSYSTEM/POPULATION LEVEL ENDPOINTS

ECOSYSTEM/ POPULATION LEVEL END-POINTS	EASY/ INEXPENSIVE	COMMENTS
ABUNDANCE	3	Relatively simple measure. Does not require species identification.
BIOLOGIC INDEXES	2	Requires comparative judgment on groups of important species.
BIOMASS	3	Relatively simple measure. Does not require species identification.
DECOMPOSITION	2	Depends on endpoint measured. At least some measures such as litter decomposition are relatively easy to perform.
DIVERSITY	1	Requires identification of both species and species distribution.
COMPETITION	1*	Difficult to measure.
INDICATOR SPECIES	2	Relatively simple to focus on the effects on a single species or groups of species as representative of the whole.
KEYSTONE SPECIES	2	Relatively simple focus on the effects on a single species.
METABOLISM	1.5	Depends on system. Easier to measure in an aquatic than a terrestrial system.
NUTRIENT CYCLES	2	Depends on which aspects of nutrient cycle is being examined.

Key: 1 - Difficult/expensive
2 - Moderate
3 - Easy/inexpensive
* - Not well studied

PRACTICALITY (cont.)

ECOSYSTEM/ POPULATION LEVEL END-POINTS	EASY/ INEXPENSIVE	COMMENTS
PREDATOR-PREY	2	Moderately easy to perform in the lab with organisms such as fish. More difficult to perform in the field.
PRIMARY PRODUCTION	2.5	Depends on how and where measures are made. Biomass is fairly easy to measure in a terrestrial system; C^{14} and O_2 techniques can be more difficult.
SPECIES RICHNESS	2	Requires identification of species.
SIMILARITY	1.5	A comparative measure. Requires collection and analysis of data from multiple sites and identification of species.
TROPHIC STRUCTURE	1	Requires identification of species and examination of feeding habits of organisms at different trophic levels.

Key: 1 - Difficult/expensive
2 - Moderate
3 - Easy/inexpensive
* - Not well studied

TABLE A-XXV

SPECIES-LEVEL RANKING
PRACTICALITY - SUMMARY

RANKING	PRACTICALITY
High - 3 -	ACUTE MORTALITY BIOCHEMICAL CHANGES MORPHOLOGICAL EFFECTS
Medium - 2 -	Carcinogenic Changes Developmental Changes Growth Physiological Effects Reproductive Effects Year-Class Distribution
Low - 1 -	Behavioral Effects Genetic Changes

TABLE A-XXVI

PRACTICALITY - SPECIES-LEVEL ENDPOINTS

SPECIES-LEVEL ENDPOINTS	EASY/ INEXPENSIVE	COMMENTS
ACUTE MORTALITY	3	Direct counts of dead organisms. This is relatively easy to measure.
BEHAVIORAL EFFECTS	1.5	Difficult to assess quantitatively due to variability over time and subject.
BIOCHEMICAL	3	Can be quantified in the lab with relative ease.
CARCINOGENIC CHANGES	2	Relatively easy to monitor in the lab or in populations where large numbers of deaths have occurred.
DEVELOPMENTAL CHANGES	2	Developmental changes can be relatively easy to monitor in the lab. May be evidenced as mortality at early life stages in the field.
GENETIC CHANGES (HEREDITABLE)	1	Requires monitoring of changes in population over relatively long periods of time.
GROWTH	2	Requires monitoring of changes over time.
MORPHOLOGICAL EFFECTS	3	Highly visible. Serves as ready evidence of adverse impact.
PHYSIOLOGICAL EFFECTS	2	Moderately easy to monitor. Includes measures such as feeding, photosynthesis, and metabolism.
REPRODUCTIVE EFFECTS	2	Depends on the measure. Behavioral changes may be difficult to monitor. Hatch success is simpler to measure.

Key: 1 - Difficult/expensive
2 - Moderate
3 - Easy/inexpensive

PRACTICALITY (CONT.)

SPECIES-LEVEL ENDPOINTS	EASY/ INEXPENSIVE	COMMENTS
YEAR-CLASS DISTRIBUTION	2	Requires identification and monitoring of different age classes. This can vary in difficulty depending on the species and the spatial and temporal distribution of age class.

Key: 1 - Difficult/expensive
2 - Moderate
3 - Easy/inexpensive

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