Using Reproductive and Developmental Effects Data in Ecological Risk Assessments for Oviparous Vertebrates Exposed to Contaminants

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CHAPTER 6

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Ecological risk assessment (ERA) is a tool often used to support the risk-based, decision-making process. An essential step in the process of applying reproductive and developmental effects data within a risk assessment context is developing an understanding of how the information is relevant to the risk-based policy question at hand. This chapter addresses how reproductive and developmental effects data from studies of contaminants can be used in ERAs in which oviparous vertebrates are primary resources of ecological and/or policy concern. We also discuss how a number of important policy, technical, and procedural topics are addressed in the course of framing and implementing the risk assessment. One of our objectives is to determine if the current ERA paradigm needs modifications to address unique risks of contaminants to oviparous vertebrates. A secondary objective is to provide background information on ERA to toxicologists, physiologists, ecologists, chemists, and modelers who are knowledgeable about oviparous vertebrates, illuminating how the results of their disciplines may be used in this process.

Historically, some adverse effects on oviparous vertebrates studied under field conditions have been attributed to exposure to synthetic chemicals, leading to the hypothesis that oviparous vertebrates are unique and may require special consideration in the ERA process. A critical examination of the species that have been adversely impacted by exposure to chemical stressors indicates that both viviparous and oviparous species have been affected. The commonalties among affected species primarily are factors of their life histories other than reproductive strategy. Often, affected species are either aquatic or feed on aquatic organisms. Generally, organ-

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isms are at greatest risk when they are at the top of the food chain, which tends to maximize exposure to persistent contaminants. Reproductive strategy per se is less of a risk factor. As described in other sections of this book, oviparous and viviparous species with "r-selected" and "K-selected" life histories have been affected by exposures to chemicals. The affected species also are at risk due to some common use patterns and properties of compounds that have caused most of the adverse, population-level effects. Chemicals that are used over wide geographic areas, such as organophosphate pesticides, or those that are common constituents in industrial waste streams, such as polycyclic aromatic hydrocarbons (PAHs), have been implicated in a number of studies. However, the most common attributes of compounds reported to cause adverse effects are their hydrophobic properties, environmental persistence, and bioaccumulative potential.

General background on ecological risk assessment

In the 1990s, ERA became the dominant, decision-making tool supporting incorporation of ecological consequences into the resolution of some types of environmental policy questions, but it is neither a new concept nor a relatively refined tool in ecological decision-making (Regens 1995). Risk assessment has been used most effectively in casualty assessments surrounding the incidence of unexpected events (i.e., automobile, health, and life insurance, flood management, and nuclear accidents). Specifically, risk assessment is used to estimate the likelihood of an event occurring that is clearly recognized as adverse. This concept has been adapted for use in decision-making with regard to ecological issues. For example, ERA may be applied to estimate the likelihood of a specific, adverse event occurring within a specified magnitude of effect, such as determining the likelihood that a species will go extinct. A key requirement is that the ecological consequence of exposure to a stressor is adverse by definition, which enables the analyst to conduct the risk assessment. In classical risk assessment, the assumption of what is adverse is relatively easy to justify: a nuclear accident is universally accepted as adverse, as is an automobile fatality, a skiing injury, a heart attack, or personal loss due to fire or theft. It has been difficult to achieve scientific and political consensus regarding an analogous list of adverse ecological events.

Ecological risk assessment has enjoyed widespread support and has become a common analytical tool in environmental policy analysis (Molak 1996), although the use of ERA continues to be controversial (O'Brien 1995; Pagel 1995). Like all analytical techniques used to assist policy analysis or decision-making, ERA has strengths and weaknesses. Ecological risk assessments are used appropriately in some circumstances but not in others (Mazaika et al. 1995). The emerging consensus appears to be that ERA will be useful in decision-making for at least a certain class of policy questions: those dealing with the effects of chemicals, especially where there is a reasonably clear legislative or policy basis for defining what is ecologically "adverse."

To be technically tractable and credible, the risk "problem" must be defined in fairly narrow policy and scientific terms (Friant et al. 1995). Often, issues related to ecological resources that are affected or utilized by diverse public and private interests quickly become complicated because of competing priorities, multiple-use strategies, and differentials between rates of resource recovery or renewal for each of the uses. Even if an issue can be defined in fairly narrow terms, the analysis may be technically and scientifically quite complex and may require sophisticated and detailed ecological information.

Most often the issues are brought together by a legislative or policy mandate. The risk problem then becomes relatively simple analytically, e.g., one chemical is the stressor causing effects on a few biological components; the effects, if present, are adverse by definition. In the absence of such a legislative or policy mandate, policy decisions related to "ecological problems" for multiple use resources appear to be simply too complicated to be addressed by traditional risk assessment methods. At best, the approaches resort to arguable assumptions about societal values and preferences or technical simplification that shrouds the essence of the decision or policy issue (Menzie 1995; O'Brien 1995; Power and Adams 1997; Lackey 1997). The traditional definition of risk, as the probability of occurrence of a defined, adverse event, often is relaxed in practice to merely predicting the likely extent of change for an ecosystem component exposed to a stressor of concern.

However, assessing the risk of contaminants on oviparous vertebrates is an area in which the decision tool, ERA, and the biota of concern, oviparous vertebrates, appear to be well matched. The efforts of this workshop are focused on effects driven by chemical stressors. In real-world applications, ecological risk assessors and managers often are confronted with the single, multiple, and cumulative effects of stressors originating from chemical, biological, and physical changes operating in the environment (Figure 6-1). This chapter will reflect the workshop focus on contaminant issues and their impact on oviparous vertebrates. Readers are reminded that in some, if not most, instances, contaminant stressors may not be among the primary risk factors that are critical to the survival or sustainability of oviparous vertebrates. Stresses that result from large-scale changes due to natural occurrences, such as floods or fires, or habitat alteration associated with agriculture, forestry, and urbanization, may be more significant than chemical effects when evaluating issues at the ecosystem scale. Therefore, approaches described herein, using a rather narrow context of contaminant effects on oviparous verte-

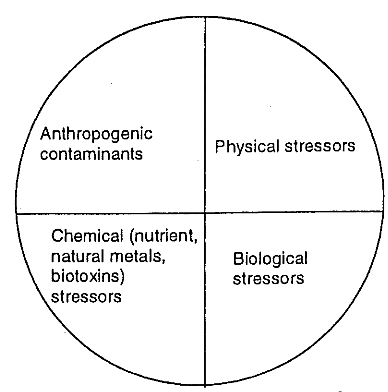

Figure 6-1 Relative contribution of stressors to ecological risk

brates, may not be directly applicable to issues framed with a much broader, and perhaps more ecologically relevant, perspective.

Nevertheless, practitioners of ERA have developed practical and quantitative approaches for assessing contaminant issues. Scientists and managers can use risk assessment tools to address the basic questions regarding potential exposures to toxic chemicals and to discern the potential for, and magnitude of, ecological change. These types of efforts have advanced our understanding of the fate and effects of chemicals released into the environment and of the dynamic biological and ecological interactions that affect the extent of impact chemicals can have. This chapter synthesizes those understandings and demonstrates how they are relevant to assessing ecological effects when information is available regarding reproductive and developmental effects of contaminants on oviparous vertebrates.

Ecological risk assessment is not the only tool that might be used to address questions regarding effects of environmental contaminants on fish and wildlife species. Others have proposed approaches based on use of the precautionary principle, analysis of ecological consequences, or economic analyses applied to ecological and other tradeoffs. Current applications of ERA provide a scientific and quantitative basis to evaluate the potential for and magnitude of adverse impacts, with some specific limitations and incorporating some uncertainties. This chapter will discuss some of these shortcomings.

Ecorisk Approaches Applied to Contaminant Effects on Oviparous Vertebrates

The U.S. Environmental Protection Agency (USEPA) has developed a framework for ERA (USEPA 1992) along with general guidance for its implementation (USEPA 1998). The conceptual ecological risk paradigm and basic approaches described in these documents have received additional elaborations and/or clarifications in peer reviewed literature (Bartell et al. 1992; Calabrese and Baldwin 1993; Suter 1993; Zeeman and Gilford 1993; Karr 1995; Mazaika et al. 1995; Molak 1996). This cumulative base of information is sufficient to address the broad array of ecological risk issues with respect to potential reproductive and developmental effects on oviparous vertebrates from exposures to contaminants.

The framework has been designed and applied with sufficient robustness to allow risk assessments to be conducted for a variety of conditions, such as transient or long-term exposure events, contaminant exposures from any number of environmental sources or pathways, and plant and animal receptors with a variety of life-history strategies. However, obtaining the relevant and appropriate exposure and response information required to execute the types of analyses laid out in these guidelines can be a major obstacle in attempting to conduct an appropriate ERA. Only when the physical, chemical, and biological data utilized in the ERA are obtained from laboratory or field studies that closely represent the conditions addressed in problem formulation can the ecological risks be expressed with significant degrees of certainty.

The various stages of organizing, collecting, analyzing, and communicating information as part of the ERA process, along with additional notations of specific considerations that might be undertaken when addressing contaminant risks to oviparous vertebrates, are presented in Table 6-1. The discussions below briefly describe this process and elaborate on ways in which the activities specifically can support the assessment of reproductive and developmental health issues.

Table 6-1 Stages of ERA and associated activities with considerations specific to oviparous vertebrates

Stage of ERA	Conventional activities	Specific oviparous vertebrate considerations
Problem formulation	Frame issue with risk manager/stakeholders; Identify assessment/measurement endpoints; Identify data needs; Develop conceptual model.	Determine how special status, commercial/ sport value considerations apply; Recognize unique exposure routes.
Exposure assessment	Identify relevant exposure pathways; Quantify oncentrations in media.	Quantify specific exposure routes for each life stage; Recognize potential for food-web exposures, especially persistent contaminants.
Hazard assessment	Assess relevancy of available toxicity data to assessment/ measurement endpoints; Evaluate dose-response relationships; Express toxicity relative to ecological receptors of concern.	Address specific roles of energy allocation and metabolism at various life stages; Take into account unique reproductive cycles, life-history strategies; Recognize contaminant stress in role of energy allocation/metabolism in oviparous vertebrate life history.
Risk characterization	Determine where and when contaminant and receptor co-occur in environment; Express contaminant risks relative to other ecological stresses.	

Problem formulation

An important early step in the ERA process is the problem formulation phase (USEPA 1992, 1998). Problem formulation establishes an understanding of the need for, and the extent of, an ERA. It evolves from iterative discussions between the risk managers requesting an assessment and the risk assessors that will perform the scientific aspects of ERA needed for risk management purposes. Elements that may be discussed include deciding what ecological components could be impacted and which ones may need to be protected; the manner in which to express or measure potential effects in ecologically significant terms; and what types of organisms, populations, communities, and ecosystems could be affected. It is during this phase of assessment that decisions to focus on oviparous vertebrates will be made because of their value to the risk managers (reflecting societal priorities), their vulnerability to the types of chemicals under consideration, or their ecological significance.

Role of risk managers, stakeholders, and policy guidance

When evaluating contaminant risks adverse to the development and/or reproduction of oviparous vertebrates, risk managers are the individuals assigned to consider the risks to those environmental components that are being or could be impacted by the contaminant-use decisions that they have made or could make. Risk managers could include corporate decision-makers considering the development of a specific product by their company, government regulators considering registration of such products, project directors tasked to clean up hazardous waste sites, or state administrators considering the ecological risks of granting air or water permits.

Assessment of the risk to oviparous vertebrates in the environment is only one of several factors that are typically considered in risk management decisions and environmental policy analyses. Other inputs such as tradeoffs between benefits and costs, conflicting societal values and preferences, or technical feasibility factors also may be considered. Other stakeholders, such as affected individuals (e.g., fishermen, landowners), state fish and wildlife officials, public interest groups, etc., also may seek to have input into and influence over some of these decisions.

Defining and improving the quality of interactions between those involved in the ERA process (the scientific risk assessors, the risk managers, and any stakeholder) is currently an actively evolving area (O'Brien 1995; Mazaike et al. 1995; Karr 1995). The social, legislative, and scientific guidance for what risk managers should consider in the environment, and the type and level of ecological change that may be accepted without being labeled and adverse change, appears highly variable (USEPA 1994, 1995d, 1997; SETAC 1997). The legislative and regulatory guidance provided to define adverse ecological change varies considerably. Some laws provide general directions on what to consider regarding protection of ecological resources from reduction, degradation, or loss in quality, quantity, or utility (Zeeman and Gilford 1993). Other laws set specific considerations and technical approaches for establishing water quality criteria that protect groups of aquatic organisms from identified priority-pollutant chemicals (USEPA 1986; Hudiburgh 1995). A few laws provide specific guidance to risk managers in defining harm and what the focus of restoration efforts should be, e.g., the Endangered Species Act (USEPA 1995d).

Deciding what to protect (and to what level)

Part of the discussions during problem formulation is deciding which oviparous vertebrates to protect from adverse developmental and reproductive effects. There are a number of reasons for focusing on oviparous vertebrates. These species can be readily observed in their habitats and some are important for economic and/or recreational purposes. Therefore, they may be highly noticed and valued by the public and natural resource managers. Any mortality, noticeable reduction in population abundance, or absence from certain environments is likely to be considered an important, adverse effect by the public and natural resource managers. In addition, some stakeholders view representatives of such highly visible and valued species as sentinels that integrate adverse effects to other species that may be masked by the dynamics of an ecosystem. Further, oviparous vertebrates are considered by some to be important sentinels for assessing larger, overall ecological effects of chemicals that may pose threats to human health (NRC 1991).

Decisions by risk managers as to what levels of chemical effects are unacceptable are likely to be somewhat variable because there is little technical or practical guidance available on this subject. Unlike human-health risk management, in which society appears to have prioritized risks of cancer at specific levels of incidence, management of ecological risks has not resulted in any such societal consensus. Scientifically, it appears to have become tractable to state that adverse ecological effects at the population level and above will be the principle areas of concern when dealing with organisms in the environment (Suter 1993; Tiebout and Brugger 1995: USEPA 1998). However, this may not be the case for highly endangered species where effects on the individual can have a disproportionate impact on a population when the number of individuals is low.

Using higher levels of ecological organization as the risk management basis, it is reasonable that defining a level of unacceptable reproductive or developmental effects likely will depend upon the specific life-history and population-dynamic characteristics of the species being considered. For example, fish that develop quickly and also spawn large numbers of eggs may be able to withstand certain localized chemical impacts, e.g., decreased egg or sperm viability. A species that requires a long time to reach adulthood and then spawns only a limited number of young may be at higher risk. Also, such long-lived species often face the increased opportunity to become exposed to chemicals, especially from persistent and bioaccumulative contaminants that might build up in body tissues over their lifetime.

Using ecologically significant measures of effect

Ecological significance commonly is applied as a subjective term because it depends on what the risk managers and risk assessors conclude are the most germane attributes. Some risk assessors may consider any incidence of bird, fish, or amphibian mortality caused by chemical contamination to be significant. A risk manager surely will ask what significance such contaminant mortality would have on the exposed populations community, or ecosystem compared with the other, ongoing stresses such as harvesting, disease, predation; this is the “so what” scenario.

A case has been made that perhaps only a certain proportion of species in an aquatic or terrestrial environment, i.e., 95%, would need to be protected (USEPA 1986;

OECD 1995). However, some might also consider subtle impacts on individual organisms as ecologically significant, e.g., effects upon behavior, development, or reproduction in a vertebrate species that is valued for various societal reasons, such as cardinals to watch, trout to catch, or frogs as an indicator of environmental problems.

This workshop has tried to develop a scientific rationale for focusing ecological concerns on contaminant impacts to reproductive and developmental processes of oviparous vertebrates. Therefore, it seems reasonable to raise ecological considerations if a chemical has been shown to cause these types of effects in the laboratory or if that chemical can be found in the environment. Ecological risk assessment is the tool to organize this information to address social and ecological priorities and to determine the likelihood that the potential for contaminant effects will be realized for ecological resources of concern.

Selecting sentinel species, surrogate species, bioindicators

As mentioned above, many oviparous vertebrates often become candidate ecological sentinels because they are sensitive to the adverse effects of chemical contaminants released to aquatic or terrestrial environments. For example, many consider salmon or trout as ideal sentinels for certain aquatic environments, hawks or other raptors as sentinels for specific terrestrial environments, and certain endangered or threatened species as representatives of larger issues surrounding preservation of unique habitats that may need special consideration. Being highly visible and/or valued often is a prerequisite for attaining sufficient attention by the public, elected officials, or organizations interested in protecting natural resources.

If oviparous sentinel species are highly visible, valued, or threatened, they may not be considered appropriate for laboratory studies. However, it is crucial in assessing risks to understand environmental exposure and dose-response relationships using typically measured endpoints such as mortality or adverse changes in development or reproduction. In many cases, suitable surrogate species will be selected to assess the possible risks of chemical contaminants to oviparous vertebrates using biological endpoints that would help express the potential for chemicals to cause adverse ecological effects.

For example, surrogate species often are selected for laboratory tests of short-term or longer-term toxic effects of specific chemicals (Smrchek et al. 1993; Zeeman and Gilford 1993; Zeeman 1997). Surrogate species are selected for these tests because they usually are amenable to laboratory culturing and because many of these species also are suitably sensitive to chemical hazards (e.g., rainbow trout are frequently sensitive to chemical toxicity and thus often are used as surrogates for all trout species, as well as for broader classes of aquatic vertebrates). Surrogate species can provide for a relatively quick, inexpensive, and reliable method to initiate the assessment of the acute and longer-term toxicity of many chemical contaminants.

Models to frame/analyze issues

The problem formulation phase of the ERA includes developing conceptual models as one way to help frame and analyze issues (USEPA 1992, 1998; Molak 1996). The type and complexity of models developed depend a great deal upon the type and complexity of the ecological problem that the risk manager has posed. Traditionally, ERAs are conducted with datasets representing 5 levels of data richness or complexity:

- screening (based on limited acute data or structure activity relationships),
- basic acute and chronic estimation studies (these include developmental and reproduction data),
- multigenerational (full life cycle, chronic effects data),
- population, and
- field.

Ecological risk assessments can range from being fairly simple and straightforward to being complex retrospective assessments. Simple, prospective assessment of the effects of one chemical product on a surrogate species may be achieved with only laboratory test data. On the other hand, complex mixtures of several different types of chemical contaminants may be assessed in an existing field situation. Such a study could assess the potential for adverse impacts over many years, incorporating information on several oviparous vertebrates as well as the invertebrates and plants that are important to the subject animals' survival in that environment.

Exposure-response assessment

Contaminant risks commonly are expressed as a probability function of exposure and resultant magnitude of effects (USEPA 1992; Suter 1993; Molak 1996). The relatively direct, uncomplicated relationships established under laboratory test conditions can provide useful insight into the potential for environmental risks. Exposure-response relationships established from field studies, although more policy relevant, carry varying degrees of uncertainty, depending on the preponderance of evidence supporting diagnosis of individual causative agents. Discussions in previous sections of this book have demonstrated the complex physical, biological, and chemical processes that can affect both exposure conditions and toxic responses of oviparous vertebrates to chemical exposure under laboratory or field conditions.

Applying these types of information to contaminant effects requires considerable evaluation as to the applicability of available data to the specific task at hand. Challenges include extrapolating data from laboratory to the field or between various taxonomic groups, clearly linking cause-and-effect information, developing a clear understanding of the toxic mode of action under consideration, and determining the ecological relevance of potential effects. The technical basis for setting a basic exposure-response relationship can become the key issue for accurately representing risks of chemical exposure to wildlife resources.

When the dose-response information necessary to conduct an ERA is focused specifically on contaminant effects on reproduction or development of oviparous vertebrates, several lines of evidence can be used. Depending on how the specific issue has been framed in the problem formulation phase, the results of laboratory tests that measure survival, growth and reproduction can be used to estimate hazard. This information may be assessed in terms of likelihood of observing impacts among exposed individuals or converted to population-level responses based on assessments of population dynamics. In this application, incremental increases in exposure are assessed in terms of the potential to affect the reproductive performance or developmental rate (efficiency) of individuals, or increased exposure is evaluated as to how it affects the ability of a population to sustain itself. Additional detail on these applications is provided in specific sections below.

Exposure

Obtaining an accurate estimate of contaminant exposure requires consideration of a wide variety of physical, chemical, and biological factors that may influence the magnitude and duration of contaminant exposure of oviparous vertebrates. The multiple life-stages characteristic of oviparous vertebrates may necessitate a more detailed and complex assessment of potential exposure pathways and vulnerable periods of exposure. In particular, some oviparous species are at the upper levels of trophic food webs. Therefore, analyses of exposures through food sources is an important consideration, especially when the contaminants under consideration are persistent and bioaccumulative chemicals.

Routes of exposure, contaminant bioavailability, and assimilation by receptor organisms can vary widely among species and habitats. Understanding the role of these factors is essential in quantitative risk assessments, since the actual duration and intensity of exposure are central factors in calculating risk. Even when duration and intensity of exposure can be quantified with confidence, low-level exposures that occur at sensitive life stages or during key developmental stages may pose significantly greater risks than do longer duration exposures to greater concentrations that might occur during less vulnerable life stages. Complete and accurate characterizations of exposure may be necessary if greater attention to the uncertainties in the risk assessment are required to resolve a risk management question.

Conceptual model of exposure/bioavailability

A number of concepts and factors must be considered when characterizing the exposure of ecological resources to environmental contaminants. Exposure of oviparous vertebrates is particularly complex because there are many potentially significant pathways to address (Figure 6-2). Bioavailability of contaminants is controlled by a number of environmental fate factors that operate in the various media where contaminants occur (i.e., air, water, soil/sediments, and food). Properties of a contaminant interact with properties of the environment to determine the status of the contaminant, including compartmentalization, chemical

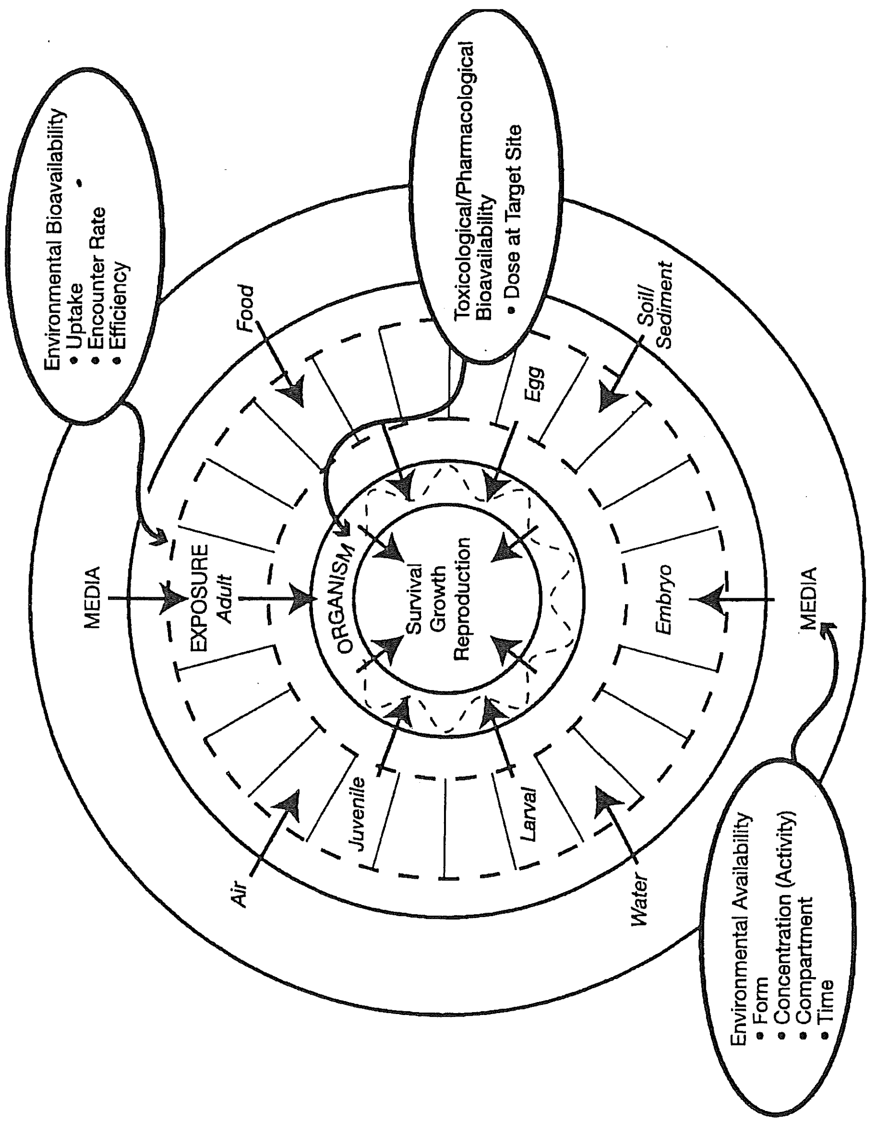

Figure 6-2 Considerations that link environmental exposures with effects of contaminants on oviparous vertebrates

form, concentration (activity), and persistence. In Figure 6-2 this is termed "environmental availability;" it is dependent on the chemical/physical properties of the compound and the environment to which it is released.

Oviparous vertebrates may be exposed incidentally or continually during various stages in their life cycle. Each stage may differ in encounter rates, uptake rates, and transfer efficiency. In all situations, exposures occur at the interface between the media and the life-cycle stages. Environmental bioavailability is the result of environmental availability and life-stage interactions. Toxicological/pharmacological bioavailability is the fraction of the dose absorbed/adsorbed by the life stages of the organism that reaches the target site that initiates biological response. The absorbed/adsorbed dose is a function of the activities specific to the organism's various life stages that can influence the effective intracellular concentrations. Thus, quantification of exposure must be conducted with significant understanding of physical, chemical, and biological dynamics. Since effects on survival, growth, and reproduction are key endpoints from an ERA perspective, understanding how the dose affects each life stage and the consequences of the effects on these ultimate measures of effect is critical. Figure 6-2 illustrates conceptually the kinds of information needed to assess exposure and effects of any contaminant to any oviparous vertebrate.

Next steps in exposure assessment

Rather than continuing to rely on simplistic assessments of exposure for any but the most simple screening assessments, the science is moving towards quantitative exposure assessments that take into account the temporal and spatial variability of exposure conditions for a population. These approaches utilize multimedia, probabilistic distributions of exposure and exposure conditions, rather than single point estimates meant to represent average conditions or values indicative of the upper end of the exposure range (Moore 1996; Power 1996; Cowan et al. 1995).

Effects

As covered by several sections of this book, reproductive and developmental effects can be characterized as occurring within acute or chronic time frames, leading to biologically significant impacts on survival, growth, or reproduction. Other sublethal changes may lead to similar adverse effects by indirect means, such as changes in behavior, physiology, or biochemistry. The key to incorporating indirect effects information into an ERA is to establish a meaningful link between the measured change in condition (e.g., physiological, biochemical, behavioral) to an ecologically relevant change.

The means by which biologically significant effects will be differentiated from ecologically significant changes is an important challenge that risk assessors must work through with risk managers during the problem formulation stage. When the risk assessment is targeted at higher levels of ecological organization (e.g., community, ecosystem), these distinctions can be particularly troublesome. Risk assessors must conduct comprehensive evaluations with sufficient completeness to ensure that measured effects can be placed into an ecological perspective relative to the temporal and spatial patterns of change that might be expected within the normal range of ecological variability. Obviously, large-scale, irreversible effects pose significantly greater ecological risks than more localized, transient changes. Changes in the reproductive capacity or incidence of developmental irregularities assessed at the population or community level of organization must be investigated with sufficient detail to allow perspective on ecological significance, providing a basis for meaningful, risk-based decision-making.

Application of Ecological Risk Assessment to Oviparous Vertebrates

General data considerations in ecological risk assessment

While many commonly used measurement endpoints are not specific to oviparous vertebrates, there are some endpoints that are particularly useful for these types of animals (Table 6-2). This list is intended to represent some, but not all, of the measurements that may be important. Depending on how the risk problem has been formulated, not all of these measurements will be needed in ERA. From an ERA perspective there is little that is unique about oviparous vertebrates, and few, if any, unique measurement endpoints would need to be selected to address most contaminant effects issues. In general, it is useful to have information on both inter- and intraspecies variability in response for the species of interest as well as estimates of the concentrations, duration, and timing of exposure. Though the specific responses to stressors might vary between oviparous and viviparous species, the fundamental concepts are not different. Both types of reproductive strategies provide opportunities to study a range of possible exposure-response endpoints that could be measured under both laboratory and field conditions. All of this information should be extrapolatable to real-world conditions and related to ecologically relevant effects endpoints.

Currently, effects on survival, growth, or development to maturity and reproductive performance are the most common endpoints considered when assessing contaminant risks for oviparous vertebrates. This information, which is based on the responses of individuals and specifically on the energetics of individual organisms, can be used to support population-level assessment endpoints. In aggregate, these types of data can provide estimates of rates of response that can be measured and expressed as ecologically relevant endpoints. The fundamental toxicological explanation behind their utility is the understanding that organisms have a limited amount of energy available to them. It takes energy to actively avoid a contaminant and to either excrete or detoxify contaminants (Forbes and Calow 1996). If indi-

Table 6-2 Example measurement endpoints that might be used to characterize contaminant effects on oviparous vertebrates and their relevance in ERA

Endpoint	Y/N
I. Survival of adults (Mortality)	Y
II. Fitness of adults	Y
Neuro-endocrine function	Y
Immune function	Y
Behavior	?
II. Growth of adults (energetics)	Y
Size	Y
Weight	Y
Lipid content	N
III. Reproductive output	Y
Fertility	Y
Fecundity	Y
Mortality of embryos	Y
Deformities (Teratogenicity)	Y
IV. Survival, growth, development of immature life stages	Y
Survival	Y
Size/weight	Y
Deformities	Y

vidual organisms need to expend energy to resist a stressor, chemical or otherwise, then less energy would be available for other functions (Calow 1994). These types of measurement endpoints are referred to as scope for growth and scope for reproduction.

Other less direct endpoints also can be measured as indicators of the potential for contaminants to adversely affect survival or reproduction. These endpoints could include behavioral changes or altered immune response that might affect the fitness of individuals or populations (Zeeman 1996). Various physiological or biochemical measures of toxicity or tissue damage could be used as measurement endpoints, as long as they are linked to the primary measurement of effect to individuals or population fitness.

The unique characteristic of oviparous vertebrates is that the embryo develops outside the body of the parent and is enclosed in a protective covering. However, there are many other important aspects of life history and physiological function that can affect how they respond to contaminant exposures and must be considered (Table 6-3). These may lead to greater or lesser exposure to stressors, depending on the specific nature of the species and stressor of interest.

Table 6-3 Characteristics that may influence the responsiveness of organisms to environmental contaminants

Characteristic	Y/N
Occurrence in higher trophic levels	Y
"r" or "K" reproductive strategy	N
Chemical tolerance	N
Immune function	N
Endocrinology	N
Exposure pathways, duration, magnitude	Y
Energy metabolism	N
Developmental stages	?
Behavior	?
Nerve function	N
Physiology	N
Biochemistry	N
Nutrition	N
Habitat	?

Issues in applied ecological risk assessment

In the application of ERA, it is important to consider that all types of information (Tables 6-2 and 6-3) may or may not be needed for making a final risk decision. Some types of needed data may not be available, requiring risk assessors to extrapolate data from other species, endpoints, or chemicals. Such extrapolation may lead to decisions based on a high degree of technical uncertainty. Alternatively, the lack of data, or availability of only highly uncertain information, may delay the decision-making process until a better scientific basis can be developed. Decisions regarding ecological risks that are perceived to be small in magnitude, localized, or of less concern to society will not require as much information and certainty as ecological risks that are perceived to be of greater severity, to be widespread in nature, or to involve oviparous vertebrates afforded special protection by law or policy.

Ecological risk assessment is practiced as an iterative and hierarchical evaluation process, especially when conducted as a prospective assessment (Zeeman and Gilford 1993). There is a premium on making accurate, scientifically defensible decisions in the most rapid, cost-effective manner possible. A tiered approach, which builds in multiple decision points for analysis of increasingly refined exposure and hazard estimates, has been an effective way to implement risk assessments. At all levels of the process, the probability of adverse consequences is expressed as a function of the degree of overlap between exposure and hazard.

In early tiers, this comparison is conducted by computing a hazard ratio, or hazard quotient, which is the quotient of some integrative measure of exposure divided by hazard. The estimate of exposure could be from a mathematical model or empirical data. Exposure estimates could be expressed as concentrations in various environmental matrices (e.g., air, water, food) or concentrations in the receptor's whole body or in specific tissues. Hazard is a measure of the magnitude of adverse effect, based on toxicity for chemical contaminants, associated with varying degrees of exposure and can be expressed as the concentration in environmental media, diet, or tissues that results in some defined level of effect. A dose or concentration that does not cause significant adverse effects is referred to as a reference dose or reference concentration and serves as a benchmark against which various exposure scenarios are evaluated.

The tiered approach begins by comparing the most relevant, readily obtained estimates of exposure and hazard. A hazard ratio of greater than 1.0 is used to indicate that there is a basis to express a level of concern (Rodier and Mauriello 1993), which might be sufficient to take some action or to justify further, more detailed evaluation of the stressor. This first phase of the risk assessment, screening, generally is based on purposefully conservative scenarios and parameter estimates that would be significantly protective of the ecological resources under consideration. Thus, exceeding a ratio of 1.0 in this tier does not necessarily mean that there would be risk but, rather, that there is reason to consider action or to further refine the risk assessment and reduce uncertainty. Generally, this is the point at which more detailed information on special exposure and effects conditions relative to oviparous vertebrates would begin to be utilized.

As currently practiced, the ERA process is dynamic and flexible. It often relies on professional judgment for assessing the relevancy of various studies and input data and for extrapolating laboratory data to field populations. This is true whether the assessment is for oviparous vertebrates or another ecological receptor. In this process, all relevant information eventually may be considered. However, there is a hierarchy or utility of the information, which can be useful for the ERA (Table 6-4).

If information that can be directly applied to the ecologically relevant processes of survival, growth, development, and reproduction of individuals is available, decisions on the probability of a contaminant affecting sustainability of populations generally are possible. The information that would be considered most relevant and given the greatest weight is empirical field data for which appropriate dosimetry and confounding factors are fully characterized. Similarly, multi-generation laboratory studies that measure a range of indicators of population sustainability and are conducted under a dosimetry regime expected in the field would receive greater weight. If these types of data are not available, information less directly applicable to the scenario under consideration is combined to provide insight into the probability of adverse population effects. The ERA process is sufficiently flexible to include a range of specific endpoints for oviparous vertebrates.

Table 6-4 Hierarchy of data potentially useful in ERA data generation and use that is currently feasible or practiced

Exposure data	Unique to O/V	Hazard data	Unique to O/V
Chemical identification name class	N	Acute toxicity Survival data Behavioral data	N
Physical chemical data Kow Koc Henry's constant	N	Chronic toxicity Survival data Growth data Developmental data Reproductive data Early life stage test Embryo-larval test	N
Persistence data hydrolysis photolysis biodegradability	N	Whole life-cycle toxicity Survival data Growth data Developmental data Reproductive data	N
Information on environmental releases chemical production use patterns	N	Population models Productivity Trophic dynamic	N
Fate models partitioning multi-media fate site specific	N	Field studies Mesocosm Controlled release Monitoring	N
Predicted environmental concentrations generic site/use specific	N		
Bioavailability bioconcentration biomagnification bioaccumulation	N		
Measured body burden whole body target tissues egg residue Lab studies Field studies Environmental monitoring	N		
Cheaper/faster analytical chemistry for exposure characterization Air Water Soil Sediments Food	N	Develop or improve surrogates available for testing Amphibians Reptiles Passerine birds	Y
		Better characterization of baseline developmental/ reproductive stages	Y
		Multigenerational toxicity tests P_1-F_1-F_2	N

Information that provides the most direct estimates of ecologically relevant endpoints would be given the greatest weight in ERAs. In this section, we provide a narrative of some examples of decisions that often are made relative to the relevance or utility of information. The problem formulation stage should delineate the extent to which oviparous vertebrates have special exposure vectors and sensitivity, information that dictates specific data acquisition tasks.

One of the greatest limitations to ERA, as with any other environmental decision-support tool, is a lack of information on the species of interest. When necessary, surrogate species can be used to estimate the hazard. Similarly, measured concentrations of exposure and dose are preferable to those estimated from models. In all cases, assumptions must be made about the extent of correspondence between the exposure conditions of the receptors of concern and the exposure-response information available to support the risk assessment. Such assumptions introduce uncertainty in the conclusions of the risk assessment. The more assumptions that are made in the assessment, the less certain the conclusions. In some cases the risk assessor may decide that there is so little information available that no estimates of risk should be made. This may result in a decision being made based on other criteria or in the decision being delayed until additional information has been generated.

Selection of exposure or toxicity data from surrogate species has been addressed in a variety of ways. Suter (1993) discusses the range of sensitivity among various taxa and the various attempts that have been made to extrapolate toxicity data among aquatic species, along with a caution that it is necessary to understand a chemical's mode of action to make appropriate extrapolations. Calabrese and Baldwin (1993) discuss derivation and extrapolation of toxicity reference values (TRVs) for birds and mammals and the accompanying cautions regarding extrapolations to other species. Because of the elaborate phamacokinetic and biochemical interactions that take place when a chemical elicits reproductive and developmental effects in oviparous vertebrates, selection and application of surrogate-species data must be conducted with considerable caution and enlightenment.

In addition, the route and timing of exposure need to be considered in evaluating the utility of various types of hazard data that may be used in the risk assessment process. For instance, egg injection studies can be conducted with most oviparous vertebrates. These types of studies have the advantage of precisely controlling the dose delivered to the embryo and may be appropriate for some persistent compounds that have their greatest effects directly on the developing embryo. However, risks from contaminants that affect reproduction by way of effects on the adult or from those contaminants that are metabolized in such a way that they are not deposited in the egg would not be accurately represented if based on egg injection studies. In that case, egg injection studies would be given less weight in the risk assessment process.

Other types of laboratory-derived data from biochemical or physiological studies pertinent to reproductive and developmental processes can serve to augment the ERA. Physiological data, life history, behavior, home range, breeding conditions, and a host of other types of ancillary information can be useful in the context of ERA (USEPA 1993b, 1993c; Pulliam 1994). Such data are particularly useful if they are mechanistic in nature, are applicable to physiological processes that are most sensitive to the type of stressor under consideration, or are unique to the receptor of concern. Even so, supportive data generally are not the key information upon which the ecological risk is based. For that reason, the need to generate these types of information de novo should be discussed early on and agreed to among those involved with the ERA and risk management decision (USEPA 1993a, 1995d).

Data analyses and applications

As noted earlier, the ecological risk assessor usually must rely on a limited set of data and is compelled to modify those data so that they are applicable to the hazard or exposure assessment at hand. It is important to emphasize that this situation is not unique to oviparous vertebrates but is commonly encountered in the field of ERA and environmental toxicology (Mayer and Ellersieck 1986; Calabrese and Baldwin 1993). Sometimes the only information available to the ecological risk assessor may be an LC50, LD50, or EC50, and this information usually comes from surrogates rather than from the species of concern (Zeeman and Gilford 1993; Stahl 1997). With the exception of the EC50, these effects levels are based on mortality and not necessarily on reproductive or developmental effects (Calow 1993). Thus, the ecological risk assessor may apply an uncertainty factor to the mortality data (LC50) and utilize this adjusted dataset in the ERA (Calabrese and Baldwin 1993) to assess the potential for long-term reproductive or developmental effects from lower-level exposures. Next, the ecological risk assessor may need to adjust the data if the study was conducted with a surrogate species (Calow 1993, 1994). At least these 2 types of data evaluations are needed for most ERAs. For more detailed reviews of toxicological data analyses, readers are referred to Calabrese and Baldwin (1993), Suter (1993), and Calow (1993).

Other important analyses of laboratory toxicity test data include deriving estimates of effects at the 20, 10, or 5% levels (i.e., the LC20, LC10, and LC5), generally to obtain estimates potentially relevant to the threshold for observing population effect levels (Barnthouse 1993). Even though there may not be quantitative responses observed at the population level to support selection of these lower-effects levels in the risk assessment, such analyses nonetheless can provide information useful in the ERA (Barnthouse 1993; Suter et al. 1987). Often these types of estimates are utilized with full recognition of the high degree of uncertainty surrounding their derivation.

In addition to short-term studies, analyses of effects of chronic exposure also produce information that can be useful for ERA (Suter et al. 1987). Chronic toxicity tests conducted in the laboratory usually incorporate exposure concentrations that tend to be more reflective of environmental exposure levels, cover a greater proportion of the animal's life stage, and, in some cases, expose sensitive life stages to the contaminant of concern. For these reasons, there generally is a lesser degree of critical analysis, estimation, and extrapolation associated with use of chronic toxicity data (Suter 1996). Chronic studies that include reproductive and developmental endpoints (e.g., egg production, hatching, survival) are some of the most useful datasets for estimating ecological risk at both the individual and population levels (Barnthouse 1993).

Empirical effects levels such as the lowest-observed-effect level, lowest-observed-adverse-effect level (LOAEL), no-observed-effect level (NOEL), and the no-observed-adverse-effect level (NOAEL) are key for ERA purposes because they can become benchmarks against which potential ecological risk can be estimated (Wagner and Lokke 1991; Suter 1993, 1996). These threshold levels of effects generally are measured directly, but other estimates of low level exposures that cause minimal or no effects (e.g., maximum-acceptable-toxicant concentration [MATC]) can be estimated based on the concentration-response or dose-response data available from chronic toxicity tests (Calabrese and Baldwin 1993).

In ERA, laboratory data are useful in the risk estimation phase, in which a quantitative expression of the magnitude and likelihood of adverse toxicological effect is developed. The ecological risk estimate derived from these data may be a point estimate or single value or a range of values, depending on the type of ERA conducted (Calabrese and Baldwin 1993). Another technique for estimating the potential risk is through the use of error propagation models (e.g., Monte Carlo simulation), which can enhance the robustness of the estimate under some conditions (Pastorok, Butcher et al. 1996). However, because the state of the science for probabilistic estimations has not yet fully matured for ERA, these types of estimates have yet to be used routinely (Suter 1993). It is expected that their development and use will increase rapidly in the next several years (Pastorok, Nielsen et al. 1996).

Ecological risk can be estimated with the hazard quotient (HQ) approach (Suter 1993; Tiebout and Brugger 1995), which has a long history of use in aquatic toxicology (Barnthouse et al. 1982; Zeeman and Gilford 1993) and is relatively well understood by both lay and technical groups. In practice, a NOAEL, LOAEL, or MATC from field or laboratory studies can become a TRV for anHQ analyses (Suter 1996). The ratio of the expected exposure to the TRV results in an HQ.

One additional important task in the risk characterization phase is to identify the uncertainties in the ERA, summarized in Table 6-5. Uncertainty is what we do not know or are unsure of and is not necessarily derived from the same sources as experimental error or variability (Stahl and Clark 1998). In the uncertainty analysis phase, the ecological risk assessor should document clearly the variability in available data, those areas in the risk assessment where data are lacking, and ways in which the absence of these data may impact the outcome of the ERA. It is important for the ecological risk assessor to point out these missing data to the risk manager, but it is not necessary that they also provide solutions to the problem. In many cases the risk manager will want to understand whether the uncertainties are significant enough to warrant further investigation or data collection. If so, then the assessment returns to the problem formulation phase, or, if the data required are easily collected and interpreted, they may be obtained without going through the major phases of the ERA framework.

Table 6-5 Summary of uncertainties encountered in the ERA of contaminants and oviparous vertebrates

Type of uncertainty	Level		
	Low	Medium	High
Extrapolation of laboratory data in non-oviparous surrogate to oviparous vertebrates of concern			x
Extrapolation of non-reproductive endpoint data to estimate reproductive endpoint or effects level		x	
Importance of maternal exposure vs. exposure to eggs or other sensitive developmental stages		x	
Understanding importance of paternal exposure on the egg and other sensitive life stages			x
Extrapolating maternal exposure scenarios to potential effects on the egg		x	
Ability to generalize effects between terrestrial oviparous vertebrates and aquatic species (extrapolating either way)			x
Understanding basic developmental and reproductive processes and linkage to potential ecological risks	x		
Understanding basic biochemical and physiological processes and their linkage to potential ecological risks			x
Extrapolation of laboratory-derived data to field situations			x

Derivation and use of relevant effects estimates from field studies

The use of effects data derived from field studies rather than to laboratory-derived data in many cases gives the ecological risk assessor information that is more applicable to a site-specific situation (Ma et al. 1991, 1996; Maughan 1993; Keddy et al. 1994). Field studies can provide direct evidence of reproductive and developmental effects, some of which can be readily observed or measured (Herricks et al. 1989; Giesy et al. 1994; Guillette et al. 1994; Hose and Guillette 1995). However, some of the effects on reproduction and development are not so pronounced and may require in-depth studies. In addition, it is difficult to diagnose the specific causative stressor, or suite of stressors, responsible for the observed effects. These types of efforts often utilize a preponderance of laboratory and field information to assess risks from contaminants found in the environment. Perhaps the most difficult aspect of using field studies is the level of effort or cost required to obtain scientifically suitable, reproducible results. In most cases, field studies need to be of sufficient length to allow researchers to understand the natural variability in a population; depending on the oviparous vertebrate involved, this can take several years (Kendall and Lacher 1994). Given the policy constraints placed on making timely decisions, seldom do risk assessors and risk managers have the option of undertaking such lengthy studies.

Types of Data/Information Needed or Useful to Assess Ecological Risks

For several reasons, ERAs should be conducted for populations of organisms rather than for individuals. The most common experimental unit upon which effects measurements are made is the individual organism. However, when statistical approaches are applied, the endpoints become population-level estimators. This is useful because ERAs seek to assign probabilities of response to given exposures, and those responses are expressed as rates. Mortality, which is a population-level phenomenon, is a crucial measurement used in ERA. Some responses of individuals such as fecundity and fertility of eggs can be expressed as rates, while others such as lethality cannot. In ERA applications, the information on population-level effects is most closely aligned with current ecological risk management policies under which contaminant releases are evaluated. Populations also are the level of ecological organization at which the technical capabilities of applied ecology are most closely linked to societal values. As one goes from population to higher levels of organization (e.g., food web to ecosystem to landscape scales) or from population to lower levels of biological organization (e.g., individual organisms to cellular level to subcellular level) it becomes increasingly difficult and complex to assess contaminant effects in terms that are relevant to societal values and policy directives (Figure 6-3).

At higher levels of organization, the potential number of stressors may be greater than those acting on a population, since the number of physical, chemical, and biological factors increases as one considers wider temporal and spatial scales associated with these larger constructs. Technically, it is more difficult to obtain credible measures of ecological effect at these higher scales. This leads to increased variability in measures of effect at the higher levels of organization and greater uncertainty regarding their predictive utility in supporting decision-making. Predicting ecological effects from studies conducted at levels of organizations below the individual organism also presents difficulty. Cellular and subcellular studies

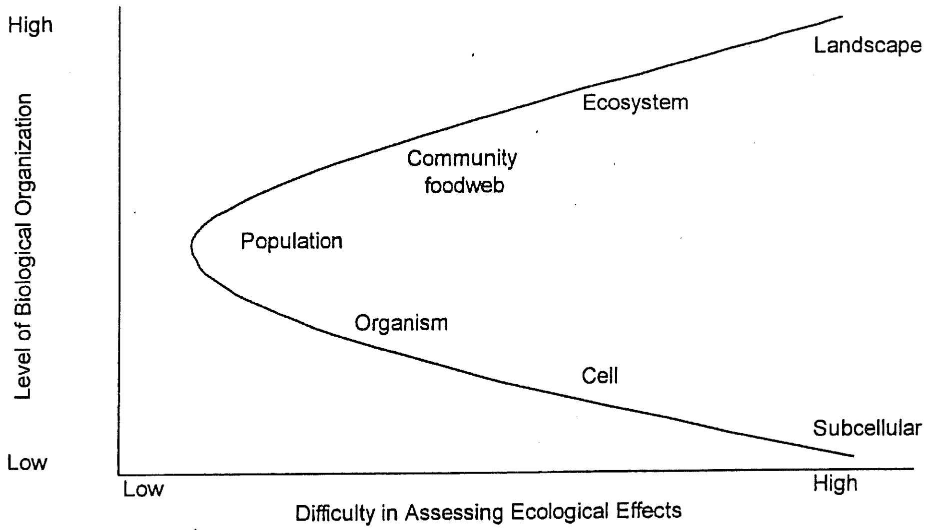

Figure 6-3 Comparison of degree of difficulty in assessing ecological effects from chemical effects data collected at different levels of biological organization

tend to be less relevant to the policy and societal values that are used to frame ERA questions than are studies conducted at higher organizational levels. Often measurements at lower levels of organization are easier to obtain and to replicate than are data collected at the higher levels. Although they may provide less variable information, these types of data contain residual uncertainty as to their utility in assessing risks relevant to ecological questions.

Historically, ecological risks have been assessed using data from various levels of ecological organization. Only recently has the practice of ERA been critically evaluated with sufficient detail and breadth of experience to allow development of a consensus regarding appropriate approaches (Suter 1993; Molak 1996; USEPA 1998). Although population-level approaches have become the most useful techniques for ERAs in contemporary practice (as depicted in Figure 6-3), there are historical, political, legislative, and technical reasons to consider conducting risk assessments at either the individual, population, food web, ecosystem, or higher levels of organization. In particular, the special status and value of some oviparous vertebrates and the technical tools available to deal with assessing contaminant effects provide opportunities for selecting any of the levels of organization, depending on the specific risk management problem to be addressed.

Risks to individuals

When is risk to individuals relevant?

Gould (1995) emphasizes evolution and natural selection acting on individuals. He said, "natural selection acts only for the benefit of individuals in reproductive success . . .Well designed organisms and balanced ecosystems are side consequences."

Because much of the available laboratory test data are generated at the level of individual organisms, assessing contaminant risks to individuals can be a relatively straightforward and rapid evaluation of the magnitude of effects that might be expected under various exposure scenarios. Because of the volume and complexity of information required to implement quantitative risk assessments at higher levels of organization, individual-level ERAs frequently are undertaken as the basis of screening-level, early tier risk assessments. In the process of emphasizing risks of impaired reproduction and development for each individual, the assessment need not become more complicated by addressing dynamic ecological processes that tend to mitigate the importance of individuals in ecological systems. If risk issues cannot be quantified or resolved with sufficient detail to remove a contaminant from further consideration, then ERAs commonly proceed to higher levels of organization.

In some cases assessing the ecological risks of contaminant exposure to individual oviparous vertebrates may be required when the receptors have been designated a species of special concern (e.g., rare/threatened/endangered species). For such species, risks must be managed to ensure full reproductive capacity and developmental potential of all exposed individuals. Even when a species is not of special concern, oviparous vertebrates often are the larger, more visible, and commonly more publicly valued natural resources that might be considered when assessing contaminant risks. Their commercial significance, recreational importance, and charismatic appeal to a wide public audience often make these fish, reptiles, amphibians, and birds highly valued receptors that frequently receive high degrees of protection relative to other ecological receptors. Thus, risk managers may decide to aggressively manage risks, regardless of the ecological significance of any reproductive or developmental change among a few exposed individuals. Risk assessors may not be able to justify setting exposures at risk levels that pose any population-level effect, knowing that the residual exposures may be sufficient to impair the reproduction or development of a few maximally exposed individuals. This type of conservative risk management approach frequently is supported by the concept that protection of all individuals in a sentinel or surrogate species will ensure the sustainability of all higher levels of ecological organization.

How does one assess risks to individuals?

In the contemporary practice of ERA, exposure assessments for individuals among a receptor species quickly moves towards defining conditions for maximally exposed individuals. Exposure conditions can be characterized over a continuum of space and time if one knows the range of territory utilized by individuals over daily, seasonal, and lifelong time frames. Often the default assumptions built into screening-level risk assessments consider limited daily or seasonal movement, low diversity of diet, and homogeneous, upper-range exposure conditions in soil, sediment, water, or air. This process of simplification greatly facilitates the estimation of the magnitude of exposure. If done within some practical limits of realism, this approach can set logical upper bounds on exposure conditions for individual organisms. Of course, exposures can be estimated more quantitatively for individuals for which there has been sufficient characterization of the quantities of environmental contaminants associated with various locations, animal activities, and exposure pathways.

An added advantage to focusing risk assessments on individuals is that much of the laboratory-derived toxicity-effects data are readily extrapolatable to risk management issues. Exposure assessments still have to take into account differences between lab and field exposure conditions (e.g., bioavailability, ionized versus unionized forms, oral versus dermal exposure). When exposure and effects can be compared quickly to existing laboratory data, the risk assessment process can be reduced to a simple mathematical exercise of generating hazard quotients. These are derived from division of environmental exposure concentrations by benchmark exposure values thought to be below levels of concern for receptor species (NOEL, TRVs, or other threshold effects estimates) under laboratory test conditions. Exceedences of effects thresholds for any individuals are deemed unacceptable risks in this approach, ensuring full reproductive and developmental capacity among the exposed receptors.

In nature, the importance of the individual to the sustainability of ecological structure and function is minimized by factors such as intra- and interspecific competition, changes in the extent or quality of habitat unrelated to contaminant effects, or natural cycles in meteorological conditions. Making a decision to manage contaminant risks to the extent that full reproductive and developmental capacity of all individuals in a receptor species will be protected often would not be cost-effective, practical, or necessary to sustain the receptor population. However, it may be warranted or required by regulatory directives or stakeholder values, since oviparous vertebrates continue to be placed at the top of the ecological hierarchy established through public values. Indeed, adverse toxicological effects observed in the field among individuals of oviparous vertebrates tend to raise public and scientific concerns about the status of the local ecosystems. Such observations can serve as an indicator of underlying contaminant effect issues.

Characterizing risks to individuals

Characterizing and communicating contaminant risks to individual organisms requires that risk assessors and risk managers appreciate the differences between ecologically significant changes and biologically significant changes. Even when there are regulatory or stakeholder directives to assess contaminant risks at the level of individual organisms, the risks should be put into an ecological context and a societal perspective. To do so would involve discussing with the stakeholder/manager the temporal and spatial significance of the contaminant risks, the extent of contaminant effects relative to baseline variability in reproduction and developmental processes, and the severity of the potential contaminant-related effects relative to other physical and biological stresses acting upon the receptors. It is resolutely important that the basic exposure-and-effects assumptions, various extrapolations, and underlying association between the risk management issue and the risk assessment endpoints be fully explained when assessing ecological risks at the level of individual organisms. There should be transparent links between risks to individuals and the issues that drive risk management actions to protect these resources at risk.

Risks to populations

When is risk to populations relevant?

Field and laboratory studies seek to provide stressor-response information for a particular receptor and stressor and, by implication, the potential for impacts on other ecological receptors likely to be exposed to the same stressor. Increasingly, ecological risk assessors and risk managers have begun to focus their efforts on potential ecological risks at the population level and above (Croonquist and Brooks 1991; Sorensen 1996). However, ecological risk assessors and risk managers should recognize that legislation, public values, economics, or other issues may compel that the focus of the assessment be at the level of the individual (e.g., threatened or endangered species) or possibly at levels of organization above the population, including ecosystem or landscape levels. Therefore, with respect to any ecological receptor, the decision to focus the ERA at the population level may not be driven by scientific reasons alone (USEPA 1995d; SETAC 1997).

How does one assess risks to populations?

Exposure assessment

With oviparous vertebrates, an exposure assessment at the population level could be approached in a variety of ways. One step, exposure-pathway analysis, is directed at understanding the total input of a particular contaminant or stressor and ways in which that exposure occurs (Ma et al. 1991; Pascoe et al. 1996). It is particularly important to understand complete exposure pathways for the egg, embryo, and juvenile stages (see Figure 6-2) because these tend to be potentially most at risk in the context of reproductive and developmental effects (Pastorok, Butcher et al.

1996). Exposure information must be relevant to the sensitive life stages, particularly if these life stages have 1) a high probability of contact or co-occurrence with the stressor, 2) unique metabolic capabilities or lack thereof (Stahl and Kocan 1986), and 3) specific dietary preferences or feeding rates (Cripe et al. 1986). Understanding bioavailability in the context of the ERA is an important concept because the amount of a substance measured in soil, food, water, sediment, or animal tissue may not be relevant to the exposure most likely to result in impacts on reproduction and development. Without understanding bioavailability, the ecological risk assessor is likely to over- or underestimate exposure (Hamelink et al. 1994), thus increasing the uncertainty in the assessment.

Another important step in understanding exposure at the population level for purposes of ERA is through the analysis of food webs (Paine 1966; Pulliam 1994; USEPA 1995a, 1995b, 1995c; Pascoe et al. 1996). There are 2 important aspects to this analysis. The first is to understand the relative contribution of the contaminant to the overall exposure to various stresses, primarily focusing on adults. The second, given the life history strategies of oviparous vertebrates, is to understand the relative contribution of the contaminant to overall stresses in the egg, embryo, juvenile, or other sensitive life stages (Pascoe et al. 1996). Having both aspects, along with additional information on bioavailability and exposure scenarios where the sensitive life stages are likely to encounter the contaminant, can reduce the uncertainty in the overall assessment.

Effects endpoints

Unless the field and laboratory studies used in the ERA measured reproductive and developmental effects, they may not be relevant to population-level impacts (Barnthouse et al. 1986; Barnthouse 1993). Various approaches to population-level impacts have been taken, depending on the type of ecological receptor and/or stressor. Abundance is one common data point that is useful in understanding the particular population being studied (Gray 1989). Other approaches have utilized microcosm-type study designs to understand the complex nature of population change resulting from exposure to a selected contaminant (Croonquist and Brooks 1991; Bengtsson et al. 1985; Graney et al. 1995). Still other common measures of population-level effects and endpoints include fecundity, age-class distributions, sex ratios, recruitment, and rates of increase (Pulliam 1988, 1994; Walthall and Stark 1997). For ERA purposes, much of the information from population-level effects can be relevant as supportive evidence of potential or actual risks, as well as providing TRVs for estimating the potential ecological risk.

Another approach to measuring impacts at the population level is through population models. These have been described in Chapter 4 and previously by others (Emlen 1989; Barnthouse 1992, 1993). In ERA, these models can be helpful in estimating potential impacts on the receptor of concern using various default and/

or literature-based inputs and, where receptor-specific data are available, in estimating potential risks to a particular population (Emlen 1989; Akcakaya 1994).

Unfortunately, there are a number of potential problems associated with population-level studies and their use in ERA, regardless of whether these studies are specific to oviparous vertebrates or not. Background "noise" or normal fluctuation in a population can be substantial (Pulliam 1988; Norris and Georges 1993) and can make it difficult for the ecological risk assessor to differentiate contaminant-related impacts from those occurring under normal circumstances. The abundance, survival, reproduction, and recruitment of a receptor may change because of factors other than exposure to the stressor of interest (Herricks et al. 1989). Underlying this change could be 1) a pre-existing loss of reproductive capacity unrelated to contaminant stress (Pulliam 1988), 2) the inability of the population to adjust to physical/chemical changes in the environment (Krebs 1972; Beeby 1993), and 3) changes in competition and predation (Connell 1961a, 1961b). In addition, there are seasonal and other cyclical changes in abundance that are influenced by the availability of food and habitat or that result from natural diseases.

An example of the difficulty in understanding population-level effects can be found in the work of Dobson and Hudson (1994). These workers found that 80% of passerine birds die before reaching age 1, and more than 70% of the variation noted in British bird survival could be attributed to temperature variation in just 2 months of the year. More quantitatively, a 1 °C change in temperature translated to a 3 to 4% change in survival in the case of British birds. Given this information, it could be difficult for an ecological risk assessor to estimate potential contaminant risk for these British birds since such a risk could be completely masked by the normal fluctuation in the population.

Another difficulty in estimating risks at the population level, whether for oviparous vertebrates or not, is that organisms vary in exposure and susceptibility to toxicants depending on age, locale, or habitat (Bowers 1994). In many cases, the ecological risk assessor may assume knowingly or unknowingly, that such variations are minimal or do not occur. Because of variations in rates of reproduction and survival, individuals contribute differently to long-term population dynamics and regulation, a fact that contradicts the implicit assumption in population-level risk assessment that all the individuals in the population respond to the stressor in the same way. Nevertheless, ecological risk assessors can draw upon demographic models where inputs to the model can be changed on the basis of field or laboratory effects, expected effects, or other points and obtain, iteratively, a possible range of potential outcomes (Akcakaya 1994). Another important point is that habitat selection can vary because not all individuals of the population will be capable of occupying all of the best habitat, particularly during breeding, spawning, and nesting periods (Neuhold 1986; Gray 1989; Suter 1990). For oviparous vertebrates, there will be some individuals that will not be able to compete as readily as others. The ability to reproduce and survive may be related to the specific habitat individuals are capable of occupying. In ERA, habitat may be just as important a variable in population effects as is exposure to contaminants.

Risks to communities

When is risk to communities relevant?

Communities are assemblages of interacting populations and have been used by ecologists as a construct to explain classical ecological hierarchy (i.e., organism, population, community, ecosystem and landscape levels). Examples of these constructs are benthic invertebrate community, fish community, and bird community). Such assemblages are artificial constructs because fish, bird, reptile communities do not interact only with like kinds but interact also with other biotic, physical, and chemical components of ecosystems during various life-cycle stages.

Assessing the ecological risks of contaminant exposures to oviparous vertebrates and subsequent effects on communities of aquatic and terrestrial organisms depends on the roles the affected populations play in physical, chemical, and biological interactions with the environment. If a population plays a keystone role in a food web and contaminants affect the population's structure and/or function, a potential exists for other populations to be affected. An example would be a contaminant's impact on the fecundity of a top-level fish predator that exerts top-down control on populations of prey species. A population decrease of such a top-level predator may release prey populations to increase in numbers, altering the structure of the fish and other aquatic populations via a cascade of interactions. Thus it appears that from an ERA perspective, the concept of community may be less useful than the concept of risk to the structure and function of food web components, which is a more scientifically tractable approach.

How does one assess risks to communities?

The major tool for assessing the potential effects of contaminants on oviparous vertebrates and subsequent impacts on food chains or food webs is trophic dynamic models. Examples of measures of effects or assessment endpoints can include allocation of numbers, biomass, growth among components of the food web, population attributes of components (e.g., age structure, abundance, sex ratios, mortality rates), or energy transfer and efficiency. Comprehensive assessment approaches such as the Index of Biotic Integrity, initially developed by Karr et al. (1986) and subsequently adapted for a variety of uses, begin to address the range of approaches that can be used to assess community impacts.

Ranking contaminant stress versus other stressors

The structure and function of food chains or food webs and their components are the consequence of not only biotic interactions but also of the combined interactions of the physical, chemical, and biotic aspects of the environment. Thus, an evaluation of the roles contaminants play in impairing food webs must include consideration of other factors affecting food webs. Figure 6-4 illustrates factors that control the biological integrity of aquatic and terrestrial food webs and ecosystems, respectively. The fate and bioavailability of contaminants in the aquatic environment are influenced primarily through the water/sediment quality component in Figure 6-4. However, the structure and function of aquatic food webs can be affected by stressors that change the energy available to food web organisms (e.g., allochthonous carbon from watershed impacted by land use), habitat limitations, amount of water available, and exotic species that compete with food-web organisms. Figure 6-4 also contains the major stressors of terrestrial systems. Plants and animals are exposed to contaminants in water, soil, and air. Habitat alteration and loss associated with land use changes can be major stressors.

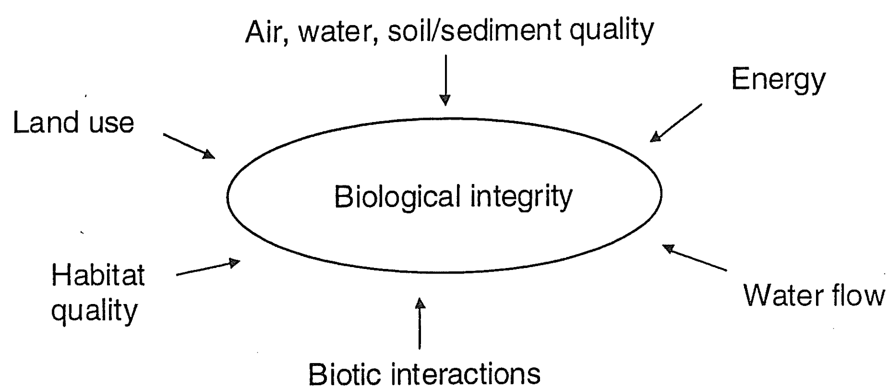

Figure 6-4 Factors controlling the biological integrity of aquatic and terrestrial systems (Redrawn from Karr 1987 ©Springer-Verlag New York, Inc.)

Risks to ecosystems

Food webs operate in the context of ecosystems. Ecosystems incorporate the physical, chemical and biotic components of the environment and are a construct to help define and delimit operational units of the environment. From an ERA perspective, ecosystems are of concern because of their structural and functional attributes. They contain valued species and perform processes important to humans and the functioning of the earth. The magnitude of the services provided are starting to be appreciated and quantified (Costanza et al. 1997). An example would be a wetland ecosystem that serves as a habitat for a wide variety of species of interest to society and that also performs a variety of process such as carbon fixation, flood storage, water purification, or nutrient attenuation.

When is the ecosystem level of risk assessment relevant?

Assessing the impacts of contaminants on development and reproduction of oviparous vertebrates on ecosystems can be relevant if results of ERAs conducted at the food web level illustrate a potentially significant impact on biodiversity and/or productivity, both ecosystem-level assessment endpoints that people care about. For example, if contaminants reduce the population of a key avian predator that is important in keeping the population of an avian prey species relative stable, controlling factors on the prey species' population are released. The prey population may expand, but most likely it will experience more chaotic population fluctuations. If the prey population plays a significant role in the pollination process for certain plant species, chaotic pollination success may result for the plant species. Thus an important ecological process and one valued by humans could be adversely impacted.

Risks to ecological landscapes

Landscapes are a high level of ecological organization and can be thought of in several contexts. From a human perspective, a landscape can be visualized as the patchwork of land uses on the surface of the earth as viewed from an airplane, aerial photograph, or satellite image. The landscape to a salamander is much different and consists of the land uses associated with its home range. Clearly, changes in the amount, position, quality, and proximity of land uses/habitat have direct ecological implications to animals and plants.

If viewed from a human perspective of landscape, other stressors such as land-use modifications by humans, natural catastrophe (e.g., hurricanes, earthquakes, or fires), disease outbreaks, chemical contaminants (e.g., air pollutants, metals, or pesticide effects on vegetation) all appear to have greater implications for creating risks to landscapes than do contaminants that affect only oviparous vertebrates. Birds, fish, reptiles, and amphibians are components of the landscape but do not appear to be significant determinants of the physical, chemical, and biological aspects of nature at the landscape scale.

Summary and Conclusions

The objective of this chapter on ecological risk assessment is to determine if the currently operable ERA paradigm needs modifications to address unique risks of contaminants to oviparous vertebrates and, if so, to explore ways to adapt the paradigm to make better assessments of risks. A secondary objective is to provide background information on ERA to toxicologists, physiologists, ecologists, chemists, and modelers knowledgeable about oviparous vertebrates, illuminating how the results of their disciplines could be used. Based on deliberations at the workshop, the risk assessment workgroup reached the following conclusions:

1) The current ERA paradigm is sufficiently robust to characterize and quantify oviparous vertebrates/contaminant effects for species with a diversity of life histories, life-cycle stages, reproductive strategies, and exposure-pathway vulnerabilities.

The ERA paradigm can be used, and is being used, to assess risks associated with developmental and reproductive issues associated with oviparous vertebrates and does not need to be modified. A diversity of assessment endpoints can be addressed using the paradigm such as ecosystem level endpoints (e.g., nutrient cycling), population-level endpoints (e.g., salmon population attributes) and organismal-level endpoints (e.g., beak deformities in birds).

2) Risk management questions that are societal-based drive the risk assessment problem formulation, which drives data and analytical needs.

A fundamental part of the ERA paradigm is the interaction of risk assessors with risk managers to collaboratively develop assessment endpoints upon which risk decisions can be made. Assessment endpoints need to be ecologically important and reflective of things people care about.

3) In general, ERA endpoints will focus on population level effects because this level is relevant to current policy and societal priorities and the scientific/technical analysis is generally tractable.

An analysis of levels of biological organization from subcellular to landscape level demonstrated that the population level is not only the most scientifically tractable but also has the greatest ability for assessing ecological risks that are relevant to the societal values and policy directives that frame resource management issues. This is not to say that ERAs cannot be made at other levels of biological organization. However, risk assessments conducted at other levels generally yield greater technical and social uncertainty and less relevancy to the scientific aspects of ecological issues.

4) Given the life histories and vulnerable life stages of oviparous vertebrates, there are unique toxicological and physiological data and contaminant-fate data that are given more weight in, and are more relevant to, ERA.

ERAs use information on survival, growth, and reproduction and data on environmental contaminant-exposure concentrations to estimate risks to populations. Toxicologists and physiologists working with oviparous vertebrates need to link contaminant effects on life stages to these endpoints. However, basic knowledge of mechanisms of contaminants on physiology, pharmacology, and toxicology of life stages is useful in decreasing uncertainty in risk assessment by contributing to the weight of evidence relating contaminant exposure to effects.

5) Oviparous vertebrates that occupy higher trophic levels are particularly vulnerable to persistent chemicals through the food web.

Examination of case studies presented at the workshop consistently illustrated that adverse developmental and/or reproductive effects were present if the oviparous vertebrate was a top predator and the contaminant was persistent and concentrated in the food web.

6) In ERA of oviparous vertebrates, there exists an operational hierarchy of data in terms of utility.

The best data consist of exposure and effects information on the population of interest. However, these data rarely exist in sufficient quality or quality. In many risk assessments a complete set of data is not needed because the contaminant exposure concentration is significantly below estimated or measured effects concentrations. However, if the contaminant exposure concentration approximates the estimated or measured effects concentration, then definitive data with low uncertainty are needed on exposure and effects.

Recommendations

The following 6 areas of research needs should receive priority. These areas have been selected to be of the most direct value in advancing our ability to perform ERAs of chemical contaminants on oviparous vertebrates.

1) Development of cheaper, quicker, more accurate analytical methods for determining chemical contaminants in water, tissues (including eggs), and soil and sediments;
2) Identification of surrogates and the development of developmental/reproduction test methods for under-represented oviparous vertebrates, particularly amphibians, reptiles, and passerine birds, and baseline effects data on contaminants;
3) Development of improved methods for multigenerational studies in oviparous vertebrates and baseline effects data on chemical contaminants;
4) Continued development of population models for finer resolution of life-stage exposure-response dynamics;
5) Development of trophodynamic models appropriate for oviparous vertebrates; and
6) Developing diagnostic tools to differentiate the effects of chemical contaminants from other stressors (e.g., exotic species, habitat alteration).

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