Chapter 24 Analysis: Characterization of Ecological Exposure

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24.1 Introduction

As noted in the previous chapter, the analysis step of ecological risk assessment includes both characterization of exposures and characterization of ecological effects. This chapter describes the approaches and methods used for exposure characterization. Chapter 25 discusses the approaches and measures used for characterization of ecological effects. The discussion in this chapter is based largely on EPA's *Guidelines for Ecological Risk Assessment*.[(1)] Readers are referred to that document for a more complete discussion of available approaches and methods.

24.2 Characterization of Exposure

Ecological exposure refers to the contact of an ecological receptor with an air toxic through direct or indirect exposure pathways. As with human health risk assessment, characterization of ecological exposure should initially evaluate (in the problem formulation phase) all exposure pathways that are potentially complete. Unlike human health exposure, ecological risk assessments will generally identify a limited number of specific metrics of exposure to actually quantify since it is not usually possible to evaluate all exposure pathways for all the species or other ecosystem attributes present in any given study area. Initially the assessors will generally consider all exposure pathways broadly, but then identify the assessment endpoints which will lead to a specific and narrowly defined set of exposure pathways to actually study in depth.

Ecological exposure pathways that are generally important for air toxics include all pathways where contaminants are taken up directly from environmental media (e.g., air, soil, sediment, and surface or rain water) for lower trophic level organisms (including plants) and ingestion of contaminated plant or animal food items for higher trophic level receptors. Pathways that may be important in specific cases include foliar and root uptake by plants, deposition and dermal exposure pathways, and ingestion via grooming, preening, and food consumption.

Once the specific set of exposure pathways to be studied are determined (and the matching assessment endpoints that are to be assessed are determined), characterization of ecological exposure is based initially on information derived from modeling and/or existing monitoring data. Later, additional modeling and/or site-specific empirical information may be obtained. The objective of the exposure characterization is to produce a summary exposure profile that identifies the exposed ecological entity, describes the course a stressor takes from the source to that entity (i.e., the exposure pathway), and describes the intensity and spatial and temporal extent of co-occurrence or contact (see Section 24.2.4.3). The exposure profile also describes the influence of variability and uncertainty on exposure estimates and reaches a conclusion about the likelihood that exposure will occur. Exhibit 24-1 provides a list of questions that can help define the specific information needed to characterize exposure.

Exposure characterization includes the following steps, each of which is discussed in a separate subsection below:[(1)]

- Quantifying releases of contaminants of potential ecological concern (COPEC);
- Estimating chemical fate and transport via modeling and/or monitoring;
- Quantifying exposure (e.g., exposure concentrations and dietary intakes);
- Evaluating uncertainty; and
- Preparing documentation.

Exhibit 24-1. Questions to Ask Concerning Source, Stressor, Exposure, and Ecosystem Characteristics

Source and Stressor Characteristics

- What is the nature of the source(s) (e.g., point vs. nonpoint vs. mobile sources)?
- What is the intensity of the stressor (e.g., the dose or concentration of a chemical)?
- What is the chemical form of the stressor and its lability as a function of local physical-chemical conditions?
- What is the mode of action? How does the stressor impact organisms or ecosystem functions?
- How does the stressor come into contact with a receptor (transport)?

Exposure Characteristics

- With what frequency does a stressor release occur (e.g., is it episodic or continuous; is it subject to daily, seasonal, or annual periodicity)?
- What is the duration of release and exposure? How long does the stressor persist in the environment (e.g., what is its half-life)?
- What is the timing of exposure? When does it occur in relation to critical organism life cycles or ecosystem events (e.g., reproduction, lake overturn)?
- What is the spatial scale of exposure? Is the extent or influence of the stressor local, regional, global, habitat-specific, or ecosystem-wide?
- What is the distribution? How does the stressor move through the environment (e.g., fate and transport)?

Ecosystems Potentially at Risk

- What are the geographic boundaries of the study area? How do they relate to functional characteristics of the ecosystem?
- What are the key abiotic factors influencing the ecosystem (e.g., climatic factors, geology, hydrology, soil type, water quality)?
- Where and how are functional characteristics driving the ecosystem (e.g., energy source and processing, nutrient cycling)?
- What are the structural characteristics of the ecosystem (e.g., species number and abundance, trophic relationships)?
- What habitat types are present?
- How do these characteristics influence the susceptibility (sensitivity and likelihood of exposure) of the ecosystem to the stressor(s)? For example, what portion of the receptor's home range is in the area of impact?
- Are there unique features that are particularly valued (e.g., the last representative of an ecosystem type)?
- What is the landscape context within which the ecosystem occurs?

Source: EPA Guidelines for Ecological Risk Assessment[1]

24.2.1 Quantifying Releases

The process used to quantify releases of air toxics for purposes of ecological risk assessment is identical to that for the human health analyses (see Chapter 7).

24.2.2 Estimating Chemical Fate and Transport

The process and methods used to estimate chemical fate and transport generally are similar to those used for multipathway human health risk assessments. Key differences and special considerations are highlighted in the subsections that follow.

24.2.2.1 Physical and Chemical Parameters

The same physical and chemical parameters identified in Chapter 17 affect the persistence of air toxics in the environment and their potential to accumulate in ecological food webs. Additional considerations are specific to ecological risk assessment.

- The bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) used to characterize ecological exposure may be different than corresponding factors used for the human health exposure assessment. For example, wildlife may eat different species of fish/shellfish than humans; these may have different BCFs or BAFs. Also, whole-fish BCFs or BAFs are used for ecological exposure rather than those specific to the parts of the fish people normally eat (e.g., fillets).

- Chemical speciation (e.g., for metals such as mercury) may be an important determinant of exposure and bioavailablity.[a]

- Fate and transport analysis may need to examine a wider range of lower-trophic level organisms to assess impacts to the communities and ecosystems of interest as well as to develop exposure estimates for ecological food webs.

24.2.2.2 Multimedia Modeling

As with human health exposure assessment, some combination of multimedia modeling and monitoring is generally used for ecological exposure assessment. The appropriate mix of modeling and monitoring will depend on the level of assessment and the risk management goals.

Modeling is relatively easy and inexpensive to implement and can be used to evaluate not only risks from current levels of contamination, but also how risks might change over time (e.g., concentrations of persistent bioaccumulative hazardous air pollutant [PB-HAP] compounds in fish may slowly increase over time in the presence of a continuous release) or as a result of

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[a] EPA's Science Policy Council is embarking on the development of an assessment framework for metals. The first step in the process is formulation of an Action Plan that will identify key scientific issues specific to metals and metal compounds that need to be addressed by the framework, potential approaches to consider for inclusion in the framework (including models and methods), an outline of the framework, and the necessary steps to complete the framework.

potential changes in land use (a change in land use might alter a number of habitat factors that influence the number and identity of ecological receptors). The modeling approach, however, has inherent uncertainties, which may lead to either over- or underestimates of exposure.

Model choices range from simple, screening-level procedures that require a minimum of data to more sophisticated methods that describe processes in more detail, but require a considerable amount of data. The same multimedia models used for the multipathway human health exposure assessment generally can be used for at least part of the ecological exposure assessment (e.g., the same models can be used to estimate concentrations in abiotic media at specific locations, whether for human health or ecological exposure assessment). However, choice of specific exposure points or areas may differ due to the focus on ecological receptors, as will the specific food webs being evaluated. Specific models may also be configured in ways that facilitate ecological exposure assessments. For example, TRIM (Total Risk Integrated Methodology) includes a fate, transport, and ecological exposure model (TRIM.FaTE) which simulates multimedia pollutant transfers and ecological receptor exposures in an ecosystem of interest (see Part III).[2] However, other approaches (e.g., Multiple Pathways of Exposure) are not specifically designed for ecological exposure assessment).

24.2.2.3 Multimedia Monitoring

The term monitoring in ecological risk assessment can also be more broadly used to mean collection of any type of empirical field data for the assessment (e.g., plant counts and spatial distribution in an assessment area). The use of monitoring in ecological risk assessment can serve a number of purposes. For example, if there is a need to reduce uncertainties in the predictive modeling approach, monitoring can be performed in various media and biota in the study area. As with human health exposure assessment, monitoring can be used to confirm or calibrate predictive modeling estimates of contaminant concentrations in media or biota.

For higher-tier risk assessments, monitoring for ecological exposures also may include site-specific toxicity or bioaccumulation studies, in which test organisms are exposed to the actual mixtures of contaminants from within the study area to develop site-specific and chemical-specific toxicological and/or bioaccumulation relationships (See Chapter 25). However, poorly designed sampling or toxicological evaluations of environmental media from the site may not allow a definitive identification of the cause of adverse response. For example, receptor abundance and diversity as demographic data reflect many factors (e.g., habitat suitability, availability of food, and predator-prey relationships). If these factors are not properly controlled in the experimental design of the study (e.g., through use of a comparison site or a gradient design that examines effects along a two-dimensional gradient downwind of sources), conclusions regarding chemical stressors can be confounded. In addition, monitoring may not provide sufficient information to develop estimates of potential risks should land use or exposure change in the future.

Monitoring techniques for ecological exposure characterization may differ from those used for multipathway human health exposure assessment. In particular, different species or components of the food web may be of concern. For example, large invertebrates such as dragonfly larvae often are a focus for ecological exposure assessments because they are important components of surface water ecosystems as well as key prey items for both aquatic (e.g., fish) and terrestrial (e.g., birds) predators.

Example Consideration in Monitoring: Soil Sampling for Ecological Risk Assessments

The depth over which surface soils are sampled should reflect the type of exposure expected in the study area, the type of receptors expected in the study area, the depth of biological activity, and the depth of potential contamination. For example, if exposures to epigeic (surface dwelling) earthworms are a concern, concentrations in the first few inches of soil are most relevant. On the other hand, if a burrowing mammal is of concern, concentrations at a depth of two or more feet may need to be estimated. Careful consideration of the size, shape, and orientation of sampling volume is important since they have an effect on the reported measured contaminant concentration values.[(3)] Selection of sampling design and methods can be accomplished by use of the Data Quality Objectives (DQO) process discussed in Chapter 7. Additional soil sampling guidance that may be consulted includes EPA's *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies* [(4)] and *Guidance for Data Usability in Risk Assessment*.[(5)]

24.2.3 Quantifying Exposure

Three elements are important components of quantifying exposure: the specific metrics of exposures that are to be used, the dimensions of exposure, and the exposure profile. Each is described in a separate subsection below. These estimates can be produced by some models such as TRIM.FaTE.[(6)]

24.2.3.1 Metrics of Exposure

Depending on the specific receptors and pathways of concern, ecological exposure is quantified generally in one of three ways.[(1)]

- Exposures to abiotic media may be evaluated using contaminant media concentrations as the **exposure concentrations** – that is, concentrations of air toxics in soil, sediment, and/or surface water at the exposure points. This is because the ecological toxicity reference levels (TRVs) used to characterize risk are based on laboratory studies that directly relate environmental concentrations in these media to adverse ecological impacts (e.g., a laboratory study that dissolves known concentrations of a chemical in water and measures adverse responses in the invertebrates or fish living in that water - the resulting concentration in water that shows no effect is then compared to modeled or monitored concentrations of the chemical in study area surface water).

- Exposures via the ingestion route of exposure may be evaluated using the **average daily dose (ADD)**, generally expressed as mg of chemical per kg of body weight per day (mg/kg-d). The general formula[(b)] for calculating ADD for ecological receptors is similar to that used for human health ingestion exposure:[(1)]

$$ADD_{pot} = \sum_{k=1}^{m} \left(C_k \times FR_k \times NIR_k \right) \qquad \text{(Equation 24-1)}$$

[b]The TRIM.FATE model[(6)] can output estimates of ingestion intake at user-designated time points in a dynamic simulation, and as an average over a user-designated period, as well as estimates for steady-state simulation.

where

ADD_{pot}	=	Potential average daily dose, expressed in units of mg/kg-day.

Chemical-related variable:

C_k	=	Average contaminant concentration in the kth type of food, expressed in units of mg/kg (wet weight)

Variables that describe the exposed ecological receptor population (also termed "wildlife exposure factors"):

FR_k	=	Fraction of intake of the kth food type that is from the contaminated area (unitless).
NIR_k	=	Normalized ingestion rate of the kth food type of a wet-weight basis, expressed in kg food/kg body-weight-day.
m	=	Number of contaminated food types

Exposure factors can be found in the EPA *Wildlife Exposure Factors Handbook*.(7)

Contaminant concentration (C_k) is commonly estimated with the use of multimedia models. In some situations (e.g., a higher tier of analysis), C_k in food has been measured directly at the point of contact where exposure occurs. An example is the use of food collected from the mouths of nestling birds to evaluate exposure to pesticides through contaminated food. Although such measurements can be difficult to obtain, they reduce the need for assumptions about the frequency and magnitude of contact.

- Exposures to some stressors are evaluated using **uptake**. Some stressors must be internally absorbed to exhibit adverse effects. For example, a contaminant that causes liver tumors in fish must be absorbed and reach the target organ to cause the effect. Uptake is evaluated by considering the amount of stressor internally absorbed by an organism and is a function of the following:
  - Chemical form of the contaminant (speciation);
  - Medium (sorptive properties or presence of solvents);
  - Biological membrane (e.g., integrity, permeability); and
  - Organism (e.g., sickness, active uptake).

Because of interactions among these factors, uptake will vary on a study-specific basis. Uptake is usually assessed by modifying an estimate of the exposure concentration indicating the **bioavailable fraction** (i.e., the proportion of the stressor that is available for uptake) actually absorbed (e.g., monomeric aluminum is generally bioavailable to certain aquatic receptors while polymeric aluminum generally is not). Absorption factors and bioavailability measured for the chemical, ecosystem, and organism of interest are preferred. Internal dose can also be evaluated using a physiologically-based pharmacokinetic (PBPK) model or by measuring biomarkers or residues in receptors.

When using a tiered approach, conservative assumptions generally are used at the screening level. Exhibit 24-2 presents examples of conservative assumptions; these are described in more detail in EPA's *Guidelines for Ecological Risk Assessment*.(1)

Exhibit 24-2. Examples of Conservative Assumptions for Ecological Exposure Estimation	
Exposure Factor	**Assumed Value**
Area-use factor (factor related to home range and population density)	100 percent (organism lives completely within area of highest exposure concentrations)
Bioavailability	100 percent
Life stage	most sensitive life stage
Body weight	minimum possible
Food ingestion rate	maximum possible
Dietary composition	100 percent of diet consists of the most contaminated dietary component
The use of conservative assumptions should be informed by study-specific information. For example, assuming 100 percent for area-use factor and diet would not be appropriate if study-specific information indicates otherwise (e.g., the receptor is only present in the assessment area part of the year). Similarly, use of the most sensitive life stage would only be appropriate if that life stage were reasonably expected to be exposed to the chemical.	

24.2.3.2 Dimensions of Exposure

Three dimensions are considered when quantifying exposure: intensity, time, and space.

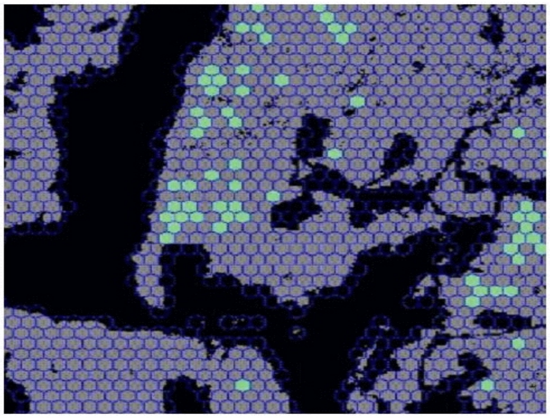
- **Intensity**. Intensity is generally expressed as the amount of chemical contacted per day. Intensity may be affected by a number of factors, including the concentration of the chemical in various media and biota and chemical form (e.g., speciation), which may affect toxicity, bioavailabilty, and/or bioconcentration.

- **Time**. The temporal dimension has aspects of duration, frequency, and timing. For air toxics assessments, intensity and time may sometimes be combined by averaging intensity over time. Due to the emphasis on persistence and bioaccumulation, the focus of the ecological exposure characterization for air toxics is generally on chronic (long-term) exposures. In using predictive modeling to estimate exposure concentrations, an average annual concentration generally is sufficient, at least for screening-level analyses. An exception would include situations where the release and the presence of ecological receptors are both periodic (e.g., releases are much higher in the spring and summer, when ecological receptors are more abundant and active). If using predictive modeling to develop estimates of the average daily dose (ADD), the duration of time modeled generally should be sufficient for concentrations of air toxics in the media and biota of concern to reach equilibrium. If the models indicate that equilibrium is not reached, the duration of time modeled generally should be at least as long as the period of time over which releases are likely to occur (e.g., the design life of a specific facility). Timing is particularly important if the exposure coincides with a sensitive life stage of the receptor organism.

- **Space**. Space is important because ecological risk assessments generally focus at the population level or higher (e.g., community, ecosystem). Therefore, space is a measure of the total fraction of the population, community, or ecosystem that is potentially exposed – a factor that will impact the overall risk characterization. Space is generally expressed in terms of areas (e.g., hectares, acres, square meters) that exceed a particular chemical threshold level. However, another important spatial consideration is the **fraction** of the overall habitat type that is potentially affected. At larger spatial scales, the shape or arrangement of exposure may be an important issue, and area alone may not be the appropriate descriptor. Geographic Information Systems (GIS) have greatly expanded the options for analyzing and presenting the spatial dimension of exposure (see Part VII of this reference manual for more information about GIS). Several recent papers discuss ways to incorporate spatial considerations in ecological risk assessments.[8]

Sometimes, temporal and spacial considerations must both be considered together. For example, in the case of acidic deposition, the andromous fish species in Maryland and other middle-Atlantic states have a special risk scenario. Specifically, their spawning run occurs at the same time when the weather pattern changes in the late winter and early spring from a coastal to a continental pattern. This increases acidic deposition to the headwaters where the spawning occurs and the eggs and hatchlings are at the most vulnerable part of their life cycle.

Using Spatial Information in Ecological Exposure Assessment



Example PATCH Output.

Many terrestrial organisms that might be evaluated in an ecological risk assessment are mobile. Where these populations spend their time depends on the locations of habitats necessary to provide food, breeding sites, and protection from predators. Behaviors such as migration also affect locations of receptor populations. Screening-level assessments usually assume that the ecological receptors of interest reside at the locations of the highest exposures modeled. In subsequent tiers of analysis, the assessor may spatially refine the exposure estimate by considering the habitat use and foraging areas of the receptor(s) of interest. GIS land cover and land use information can be used to estimate where an ecological receptor is likely to reside or breed. For example, EPA's Western Ecology Division of the National Health and Environmental Effects Laboratory developed a model called Program to Assist in Tracking Critical Habitat (PATCH), which can be used to generate "patch-by-patch" descriptions of landscapes, assessments of the number, quality, and spatial orientation of breeding sites, and map-based estimates of the occupancy rate. In the example output shown here, the medium grey areas denote significant/acceptable habitat and the lighter gray (or light green) areas denote areas suitable for breeding. This information can be used to identify where the ecological receptors are likely to reside or breed, and the modeled exposure concentrations at those locations can be used in the risk characterization calculations. The PATCH software and user's guides are available at: http://www.epa.gov/wed/pages/models/patch/patchmain.htm.

24.2.3.3 Exposure Profile

Questions Addressed by the Exposure Profile

- How may exposure occur?
- What may be exposed?
- How much exposure may occur?
- When and where may exposure occur?
- How may exposure vary?
- How uncertain are the exposure estimates?
- What is the likelihood that exposure will occur?

The final product of the ecological exposure assessment is an exposure profile. Exposure is generally described in terms of intensity, space, and time, and in units that can be combined with the ecological effects assessment (see Chapter 25). The exposure profile identifies the receptor and describes each exposure pathway as well as the intensity, spatial extent, and temporal extent of exposure. The exposure profile also describes the impact of variability and uncertainty on exposure estimates and reaches a conclusion about the likelihood that exposure will occur. Depending on the risk assessment, the exposure profile may be a written stand alone document or a module of a larger document. In either case, the objective is to ensure that the information needed for risk characterization has been collected, evaluated, and presented in a clear, concise, and transparent way. The exposure profile also provides an opportunity to verify that all of the important exposure pathways identified in the conceptual model (i.e., those that support an evaluation of the assessment endpoints) were evaluated.

24.2.3.4 Evaluating Variability and Uncertainty

The exposure profile described in the previous section should aid understanding of how exposure can vary depending on receptor attributes (exposure factors) or stressor levels. Variability can be described qualitatively, by using a distribution or by describing where a point estimate is likely to fall on a distribution. EPA policy recommends the use of both central tendency and high-end exposure estimates.[9]

The exposure profile also should summarize important uncertainties (e.g., lack of knowledge), including:

- Identification of key assumptions and how they were addressed;
- Discussion (and quantification, if possible) of the magnitude of modeling, sampling, and/or measurement error;
- Identification of the most sensitive variables influencing the exposure estimate; and
- Identification of which uncertainties can be reduced through additional data collection, modeling, or analysis (e.g., in a subsequent tier of analysis).

Professional judgment often is needed to determine the uncertainty associated with information taken from the literature and any extrapolations used in developing a parameter to estimate exposures. All assumptions used to estimate exposures should be stated, including some description of the degree of bias possible in each. Where literature values are used, an indication of the range of values that could be considered appropriate also should be indicated. The uncertainty and variability associated with ecological effects criteria must also be taken into consideration. A more thorough description of how to deal with variability and uncertainty in the risk assessment process is provided in Chapter 31.

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