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Generic Ecological Assessment Endpoints (GEAEs) For Ecological Risk Assessment: Second Edition With Generic Ecosystem Services Endpoints Added

Risk Assessment Forum
U.S. Environmental Protection Agency
Washington, DC 20460

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PREFACE

Ecological risk assessment (ERA) is a process for evaluating the likelihood that adverse ecological effects may occur or are occurring because of exposure to one or more stressors. A critical early step in conducting an ERA is deciding which aspects of the environment will be selected for evaluation. This step is often challenging because of the remarkable diversity of species, ecological communities and ecological functions from which to choose and because of statutory ambiguity regarding what is to be protected. The purpose of this document is to build on existing U.S. Environmental Protection Agency (EPA) guidance and experience to assist those who are involved in ERAs in carrying out this step, which in the parlance of ERA is termed "selecting assessment endpoints." The document describes a set of endpoints, known as generic ecological assessment endpoints (GEAEs), that can be considered and adapted for specific ERAs.

This document was prepared under the auspices of EPA's Risk Assessment Forum. The Risk Assessment Forum was established to promote scientific consensus on risk assessment issues and incorporate this consensus into appropriate risk assessment guidance. To accomplish this, the Forum assembles experts from throughout EPA in a formal process to study and report on these issues from an Agency-wide perspective. The document is intended to supplement the use of the Forum's *Guidelines for Ecological Risk Assessment* (U.S. EPA 1998a). Following the publication of the guidelines, a subsequent EPA colloquium sponsored by the Forum identified high priorities for ERA, including among them the need for Agency-wide GEAEs, and directly led to the development of this document.

The primary goal of this document is to enhance the application of ERA at EPA, thereby improving the scientific basis for ecological risk management decisions. The document, however, is not a regulation, nor is it intended to substitute for federal regulations. Rather, it describes general principles and is not prescriptive. It is intended to be a useful starting point that is flexible enough to be applied to many different types of ERAs. Risk assessors and risk managers at EPA are the primary audience; the document also may be useful to others outside the Agency.

It has become increasingly apparent that decisions to protect the environment can be more effective when benefits to humans are considered. Accordingly, the concept of ecosystem services has become progressively more common in the research literature and is beginning to be applied by EPA. Ecosystem services, however, have been used rarely by the Agency in policy documents or decision making. The subject of ecosystem services was recommended to the Risk Assessment Forum as a priority for guidance development during a colloquium of the Agency's ecological assessors (U.S. EPA 2010). The Risk Assessment Forum organized a technical panel to address ecosystem services. That panel first prepared a white paper explaining the concept and its relevance to the Agency's ERAs (U.S. EPA 2015), which served as the technical background document for this expanded second edition of the GEAE guidelines.

This second edition adds a table of generic ecosystem services that can be used as endpoints in ERAs performed by or for the Agency. It also explains the nature and utility of ecosystem services endpoints and explains how they might be used in individual assessments. These ecosystem services generic endpoints supplement the conventional generic endpoints by indicating how the loss of ecological entities can result in the loss of associated ecosystem services. Assessing risks to ecosystem services can (1) highlight potential assessment endpoints such as nutrient cycling, carbon sequestration, and soil formation that are not conventionally considered; (2) help communicate the importance of environmental protection to stakeholders and decision makers; and (3) provide input to subsequent ecological benefits assessments. Ecosystem services endpoints can make ERAs more relevant to decision makers and stakeholders whose concerns may be anthropocentric and can provide an output that is more useful to economists who perform cost-benefit analyses than conventional endpoints alone.

ACRONYMS AND ABBREVIATIONS

CAA	Clean Air Act
C-GEAE	conventional generic ecological assessment endpoint
CWA	Clean Water Act
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ES-GEAE	ecosystem services generic ecological assessment endpoint
ESA	Endangered Species Act
GEAE	generic ecological assessment endpoint
NEPA	National Environmental Policy Act

1. INTRODUCTION

In the practice of ecological risk assessment (ERA), assessment endpoints are the valued attributes of ecological entities upon which management actions are focused (U.S. EPA 1998a). Because not all organisms or ecosystem features can be studied, regulatory agencies and other decision makers choose from among many candidate endpoints. Suter (2000) and a U.S. Environmental Protection Agency (EPA or the Agency) colloquium in 1998 suggested ERA and management within EPA would be improved by developing a set of generic assessment endpoints that cover EPA's range of concerns for the protection of ecological entities and functions.

In response to that suggestion, the first edition of this document presented a set of generic ecological assessment endpoints (GEAEs) that provided examples of endpoints applicable to a wide variety of assessment scenarios. It also provided guidance for using these GEAEs to develop robust, assessment-specific endpoints. The role of assessment endpoints in ERA is discussed in Text Box 1. The application of GEAEs to the process of generating and using assessment endpoints in ERAs is illustrated in Figure 1-1.

> **Text Box 1. The Role of Assessment Endpoints in EPA's Framework for ERA**
>
> ERAs are preceded by a planning phase in which decision makers, risk assessors and, as appropriate, interested parties define the management goals. The goals are broad statements of desired conditions such as "restore the wetlands" or "sustain the trout population."
>
> The planning phase is followed by the problem formulation phase in which the assessors define the assessment endpoints based on the management goals. The assessment endpoints are specific entities and their attributes that are at risk and are expressions of a management goal.
>
> The analysis and risk characterization phases of the risk assessment are devoted to estimating the nature and likelihood of effects on those endpoints.
>
> Finally, risk communication involves conveying those results and associated uncertainties, as well as explaining their implications. These processes are explained in *Guidelines for Ecological Risk Assessment* (U.S. EPA 1998a).

The Agency's *Ecological Benefits Assessment Strategic Plan* recommended that GEAEs be extended to include ecosystem services (U.S. EPA 2006). Subsequently, an EPA colloquium called for the development of guidance for the use of ecosystem services in ERA (U.S. EPA 2010). That priority was supported by the Ecological Processes and Effects Committee of the Science Advisory Board (Swackhamer and Burke 2012). Additionally, an October 15, 2015 Executive Memorandum directs federal agencies to develop and institutionalize policies to promote consideration of ecosystem services, where appropriate and practicable, in planning, investments and regulatory contexts (Donovan et al. 2015). As a result, this second edition of the GEAE document presents ecosystem services generic endpoints and explains how ecosystem services can be used as ecological assessment endpoints.

1.1. Definitions of Assessment Endpoints

An assessment endpoint is defined in *Guidelines for Ecological Risk Assessment* (U.S. EPA 1998a) as "an explicit expression of the environmental value to be protected, operationally defined as an ecological entity and its attributes." An ecological entity, for example, might be an important fish species such as coho salmon, with its attributes being fecundity and recruitment. Effects on assessment endpoints are estimated using measures of effects (Text Box 2). The guidelines provide three selection criteria: ecological relevance, susceptibility (i.e., exposure plus sensitivity) and relevance to management goals. Selecting appropriate assessment endpoints is a critical step in ensuring that an assessment will be useful to risk managers in making informed and scientifically defensible environmental decisions.

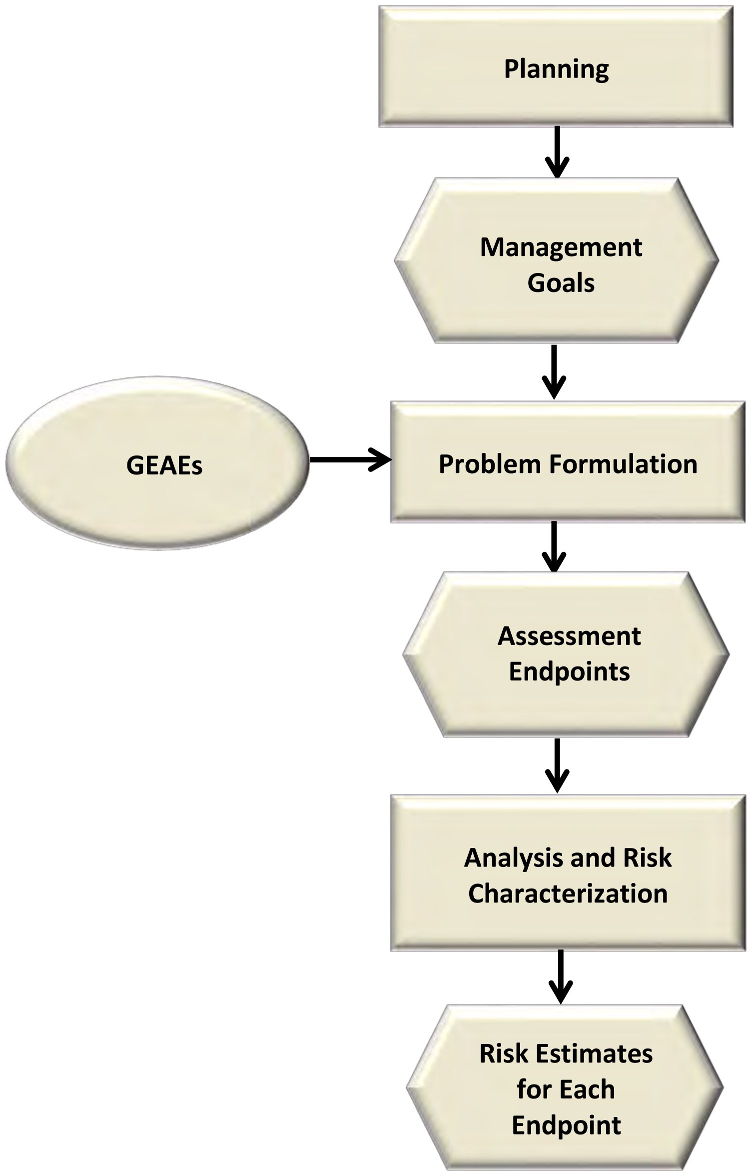

Figure 1-1. Application of GEAEs in Risk Assessment. This figure shows the process of generating and using ecological assessment endpoints, as well as how GEAEs are used along with management goals in the selection of assessment endpoints during problem formulation. Rectangles represent assessment processes and hexagons represent the products of those processes.

GEAEs are assessment endpoints that are applicable to a wide range of ERAs because they reflect the programmatic goals of the Agency, are relevant to a wide array of environmental issues and may be estimated using existing assessment tools. GEAEs do not comprise a complete list of what is or, by exclusion, what is not protected by EPA. They are not specifically defined for every conceivable case, and some ad hoc elaboration by users is needed to make them specific to the circumstances of the assessment (see Section 2.1). Furthermore, although GEAEs are not goals or objectives, they should be related to goals or objectives when such are known. For example, a generic endpoint could be created for endangered species, but the specific species of concern would be defined during problem formulation, and attributes of the species could be selected to fulfill the goals of the Endangered Species Act (ESA),[1] the recovery plan for the species and the objectives of the particular assessment.

The conventional GEAE list in Chapter 2 was inspired by prior lists of generic endpoints for regional assessments (Suter 1990), population assessments (Suter and Donker 1993), assessments of hazardous waste combustors (U.S. EPA 1999e) and assessments of contaminated sites in Alaska (ADEC 2000). In addition, examples of ecological assessment endpoints evaluated within certain EPA programs have been highlighted in prior EPA documents (U.S. EPA 1994; U.S. EPA 1997b; U.S. EPA 1997d; U.S. EPA 1998a). These examples are presented in Appendix A. Since the publication of the first edition of this document in 2003, the GEAEs have been published in a peer-reviewed journal (Suter et al. 2004) and have been used outside of EPA (e.g., Efroymson et al. 2005), but no additional lists of generic endpoints have been found.

Text Box 2. The Relationship of Measures of Effects with Assessment Endpoints

Measures of effects (also known as measurement endpoints) are the results of tests or observational studies that are used to estimate the effects on an assessment endpoint from exposure to a stressor. For example, a conventional measure of effect from an acute lethality test is the median lethal concentration (LC_{50}), which might be used to estimate the risk of a fish kill (an assessment endpoint) from exposure to a spill of the tested chemical.

Measures of effect and assessment endpoints may be expressed at the same level of organization (mortality is an organism-level attribute). The same measure of effect may be used, however, with considerably greater uncertainty, to estimate risks to a population-level assessment endpoint (abundance of a fish species) or a community-level endpoint (number of species).

The first edition also clarified some concepts in ways that have proven useful to ecological assessors. The concepts of assessment population and assessment community (Section 2.2) now are employed in environmental assessments and have been cited in the literature (Barnthouse et al. 2008; Munns and Mitro 2006; U.S. EPA 2009b; von Stackelberg 2013). In addition, the clarification contained in the first edition of the relationship between the assessment endpoint entity/attribute and the levels of ecological organization has been used to respond to those who claim that Agency policy and practice is to protect individual nonhuman organisms (Suter et al. 2005).

1.2. Potential Uses for Generic Assessment Endpoints

The sets of generic assessment endpoints proposed in Chapters 2 and 3 of this document can be useful for risk assessors and managers involved in planning and performing ERAs within various EPA program and regional offices. In particular, this document can be consulted during the problem formulation stage of ERAs to assist in developing assessment endpoints that are useful in EPA's decision-making process, practical to measure and well defined. In addition, the specific environmental laws, precedents and other polices, presented in Appendix A, provide the supporting information for the conventional generic endpoints in Chapter 2 that are also useful in supporting assessment-specific endpoints.

Individual EPA program and regional offices may have specific uses for these generic endpoints beyond ERAs. For example, water quality management programs may use this information during the process of refining designated aquatic life uses in state and tribal water quality standards, when reevaluating or developing guidance for consistent and environmentally relevant monitoring programs and in interpreting

[1] Endangered Species Act of 1973, 16 U.S.C. § 1531 et seq.

and implementing narrative water quality standards. In particular, this set of generic endpoints may be useful within the context of a total maximum daily load for a water body that has been listed for nonsupport of aquatic life, but for which the state's water quality standards include no numeric biocriteria. This set of generic endpoints can be used to assist in the selection of appropriate ecological response variables or to judge the effectiveness of the pollutant reductions.

Ultimately, generic assessment endpoints can have several other uses within the Agency, such as in the following:

- Giving the decision maker a set of commonly used ecological endpoints that could give decision makers the same level of confidence as the familiar human health endpoints.
- Providing a threshold for prevention of environmental degradation by ensuring that certain values are at least considered for assessment.
- Complying with legal requirements.
- Improving the consistency of ERA and ecological decisions.
- Serving as models for site-, action- or region-specific endpoints.
- Performing screening ERAs for which endpoints may need to be developed rapidly with little input from a decision maker.
- Providing clear direction for the development of methods and models.
- Facilitating communication with stakeholders by creating a set of familiar and clear generic endpoints.
- Reducing the time and effort required to conduct assessments.

These uses are described more fully in Suter (2000).

It is important to emphasize that the generic assessment endpoints are not mandatory or applicable to all assessments. These particular generic endpoints should be used only when and where they are relevant. EPA anticipated in the first edition that, in many cases, the endpoints derived from the generic assessment endpoints would be supplemented by other assessment endpoints that are relevant to the specific stressor or ecosystem. That has proven to be true in practice. Additionally, the initial set of GEAEs were anticipated to be reviewed, modified and supplemented as experience is gained in applying and interpreting them in a variety of natural conditions and regulatory contexts (Chapter 5). Generic ecosystem services (Section 1.4) constitute the first such addition.

1.3. Criteria for Generic Ecological Assessment Endpoints (GEAEs)

Like assessment endpoints developed for specific risk assessments, the GEAEs presented in this document have a sound basis in ecological theory and are intended to be useful in EPA decision making. The criteria provided below are used in this document for evaluating potential GEAEs. They are independent of specific assessment situations and in that way differ from the criteria that should be used in developing assessment-specific endpoints (Chapter 4).

1. **Generally useful in EPA's decision-making process.** Usefulness may be indicated by the language found in the statutes, treaties and regulations that the Agency implements or with which it

complies. Judicial decisions also indicate how the values defined by statutes may be translated into generically useful endpoints. In addition, Agency guidance, guidelines, protocols and official memoranda indicate potentially useful endpoints. Finally, various EPA actions that were based on ecological protection (i.e., Agency precedents) provide evidence of general utility for GEAEs. These various sources of environmental policy are summarized in several EPA reports (U.S. EPA 1994; U.S. EPA 1997d). Additional sources are referenced in Appendix A. Note that the reliance on available policy and precedent in this document should not suggest a similar restraint on risk assessors and managers in practice. EPA has a broad mandate to protect the environment that can support the use of novel endpoints in individual assessments (Chapters 4 and 5).

2. **Practical.** Methods used to estimate risks to the endpoint entity and attribute should be available and reasonably practicable in various assessment contexts. This requires methods that directly measure or observe the endpoint's attributes or estimate them using a combination of measurements and models. This does not, however, require that a GEAE be useful for all situations. Some GEAEs will not be implementable for some taxa or ecosystems, but they should be practical in many situations.

3. **Well defined.** At a minimum, a GEAE must include an entity and an attribute of that entity (U.S. EPA 1998a). The entity and attribute should be explained clearly in a way that is understandable to the public and decision makers, as well as unambiguous to environmental scientists. A definition should be supported by a clear explanation of the endpoint's relationship to the Agency's management goals and programmatic applications.

Support for the first two criteria (usefulness and practicality) is presented in Appendix A and summarized in Table 2-2. The third criterion (that GEAEs be well defined) is supported by the definitions in Section 2.1and supplemented by the background material in Appendix A.

1.4. Ecosystem Services as Assessment Endpoints

Although a criterion for assessment endpoints is that they are valued, the nature of the values is not a required part of their definition (U.S. EPA 1998a). Rather, assessment endpoints have been defined as an ecological entity and attribute, as described earlier in Section 1.1. Going beyond conventional assessment endpoints to describe the valued attributes of endpoints, however, may be useful or even essential to success in informing a decision. For example, the Clean Air Act (CAA) describes ecological goals in terms of human welfare. The concept of ecosystem services provides a conceptual basis for the extension from ecological attributes to human values.

Ecosystem services are the outputs of functioning ecosystems that contribute to human well-being now or have the potential to contribute in the future (U.S. EPA 2016). This definition includes the provisioning of goods (e.g., food, fiber, timber, fuel, clean air and water), ecological processes (e.g., regulation of biological productivity, material cycling, climate) and other attributes such as aesthetic features.

A set of generic ecosystem services endpoints (ES-GEAEs) is presented in Chapter 3 and summarized in Table 3-1. Like the conventional generic assessment endpoints (C-GEAEs), the ES-GEAEs are defined by an entity and an attribute. Also like the C-GEAEs, the ES-GEAEs are broad and will need to be made specific when applied to individual assessments.

The status of the ES-GEAEs in ERA practice differs from that of C-GEAEs. The C-GEAEs are solidly based on precedent and language in laws, regulations, guidance and practices. Because the inclusion of ecosystem services endpoints in ERA has been limited, the ES-GEAEs do not have the same foundation as C-GEAEs. No law or regulation calls for assessment of risks to ecosystem services, but an Executive

Memorandum, released while this document was in review, encourages their use (Donovan et al. 2015). Ecosystem services have been assessed in Integrated Science Assessments and Welfare Risk and Exposure Assessments in recent reviews of the National Ambient Air Quality Standards (Rea et al. 2012; U.S. EPA 2009a; U.S. EPA 2016). Finally, all C-GEAEs are practical in that demonstrated methods are available for estimating changes in them in response to perturbations. That is not true of all ES-GEAEs. Some quantitative methods exist for estimating ecosystem services, some methods are qualitative and others require additional research before they can be used (U.S. EPA 2016). As ES-GEAEs are used, they will become more mainstream and provide additional information to the decision maker.

The uses and benefits of ecosystem services as assessment endpoints are explained in the technical background white paper (U.S. EPA 2016) and summarized below:

- **Support for cost-benefit analysis.** Ecosystem services generate natural goods and other benefits that may be monetarily valued in cost-benefit analyses. Such analyses are prompted by Executive Order 12866, which requires an examination of the environmental benefits and costs of all federal regulatory actions that are economically significant (i.e., the costs of that action are expected to be greater than $100 million annually).[2]

- **Assessment of risks to public welfare.** Ecosystem services generate benefits to the public that enhance welfare. In particular, the CAA calls for protection from known or anticipated adverse effects to public welfare via secondary National Ambient Air Quality Standards.[3]

- **Clarifying the value of environmental protection.** Although most ERAs do not support cost-benefit analyses or address mandates to protect public welfare, the decision-making process may be enhanced by clarifying the utilitarian benefits of environmental protection. For example, many ERAs use benthic invertebrates as endpoint entities but decision makers and stakeholders often do not understand that those organisms are food for fish and other vertebrates, much less that they contribute to human well-being through the production of ecosystem services (U.S. EPA 2016). Enumeration of the services provided by the benthic invertebrate community can strengthen the basis for a protective decision and enhance communication of the benefits of protection to the public (Forbes and Calow 2012).

- **Support natural resource damage assessments.** The estimation of damages to natural resources under Superfund and under the Oil Pollution Act[4] is performed by natural resource trustees. Although EPA has not traditionally been designated as a trustee, Agency assessments could be more useful to the trustees if they include ecosystem services endpoints (Munns et al. 2009; U.S. EPA 2016).

1.5. Relationship of Conventional and Ecosystem Services Endpoints

C-GEAEs and ES-GEAEs serve different but complementary purposes. The conventional assessment endpoints are required for all ERAs and are sufficient for many of them. They are required because they represent the ecologically important and susceptible entities and attributes that require protection under the laws and regulations supported by ERA. Ecosystem services endpoints are not required but can be useful when the benefits of protection must be estimated or, more generally, when the benefits to humans are not obvious and must be described to decision makers, stakeholders or the public to help justify or inform a decision. Most people, even many decision makers in environmental agencies, would like to

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[2] Exec. Order No. 12,866, 58 *Fed. Reg.* 51735 (Oct. 4, 1993).

[3] Clean Air Act of 1963, 42 U.S.C. § 7401 et seq.

[4] Oil Pollution Act of 1990, 33 U.S.C. § 2701 et seq.

know how environmental protection might benefit humans, but they do not know enough about the services that ecosystems and their component species perform to make that extrapolation themselves.

One might be tempted to switch entirely to ecosystem services endpoints because they explicitly protect the services and implicitly protect the ecological entities that perform those services. Protecting ecosystem services endpoints may not, however, protect the conventional endpoints. The level of exposure and the sensitivity of an ecological endpoint are not correlated with the degree to which they provide services. Also, ecosystem services endpoints could have paradoxical implications for environmental management. In particular, ecosystem services can increase as the ecosystem is exploited and decrease as it is protected. In one case, a trout population provided no ecosystem services if fishermen did not harvest the fish; it provided more ecosystem services if a road and parking area were constructed to increase use; and it provided even more services if it were changed from catch and release to catch and consume (Ringold et al. 2013). Similarly, the Mauripas Swamp in Louisiana provided $215,000 per year in water treatment services when it received untreated effluent, but the value of that ecosystem service it provided was reduced to zero when it no longer received the effluent (Kareiva and Marvier 2011). Whereas protecting highly used resources is important, EPA also protects unused populations and ecosystems. Similarly, rare species may provide fewer ecosystem services simply because of lower abundance of the service-providing organisms. Therefore, an abundant species might be deemed more worthy of protection than a rare species that can provide the same service. We consider the benefits of use (as measured through ecosystem services) and nonuse values.

If ecosystem services are used to inform decision making (as opposed to only clarifying the potential benefits of conventional environmental protection), tradeoffs among multiple potential services may be problematic (Adams 2014; Menzie et al. 2012). For example, herbicide runoff into a lake may reduce algae and increase water clarity. An increase in the ecosystem services of clean water for swimming and boating may occur concurrently with a diminishing service of recreational fish abundance. Similarly, dredging a wetland may increase the sediment retention service while diminishing the waterfowl habitat service. In conventional assessments, herbicide runoff would be considered only as a toxicological alteration of a lake ecosystem, and wetland disturbance would be considered only as a wetland loss that requires mitigation. Without considering ecosystem services, the potential benefits of the herbicide or of dredging normally would not be included in an ecological risk assessment. Also, analysis should consider that these alternative services of different ecological conditions may be distributed differentially among socioeconomic classes and ethnic groups (Adams 2014).

Although the same organisms, populations or communities can be involved in conventional and ecosystem services endpoints, they are not redundant because they can address different aspects of the environmental entities and serve different purposes. Conventional endpoints should be included to focus the assessment on the environmental entities and attributes that are most at risk. Also, they are assessed to meet the mandates of environmental laws and regulations. Ecosystem services endpoints can be added to expand the assessment to include services that humans might lose if those attributes of the environment were not protected. They can provide greater relevance to public concerns and serve as input to economic benefit analyses when they are required.

2. CONVENTIONAL GEAEs (C-GEAEs)

This chapter presents EPA's current set of C-GEAEs to be considered for the uses described in Section 2.1. As stated, these C-GEAEs are not exhaustive or mandatory, but rather are provided to assist EPA program and regional offices, researchers and decision makers who are involved in protecting the nation's ecological resources. The entities and attributes in the current set of C-GEAEs are presented in Table 2-1. The specific taxa, communities or ecosystems for which policy or precedents were identified are listed in the last column of the table. The C-GEAEs are defined in Section 2.1, and the basis for the terms "assessment community" and "assessment population," which are used in the definitions, is explained in Section 2.2. Information concerning laws, regulations and precedents that support the selection and use of these C-GEAEs is presented in Appendix A and summarized in Table 2-2. A general discussion of the values related to these C-GEAEs is presented in Appendix B. Other potential C-GEAEs that were promising but did not fully meet the criteria in Section 1.3 are discussed in Chapter 5. The list of C-GEAEs has not been updated for this second edition because the second edition's purpose is to add ES-GEAEs (Chapter 3).

These C-GEAEs are not always biologically distinct, but the apparent overlaps are justified in pragmatic terms, as noted in Text Box 3. For example, the generic endpoint "population extirpation" is an extreme case of the generic endpoint "population abundance." The extirpation of a population, however, is qualitatively different from a simple percentage loss of abundance. The implications of reductions in fish abundance include a loss of fishing income, but extirpation means an end to the fishery. In addition, establishing that extirpation has occurred (e.g., the fish are no longer caught) or will occur (e.g., the trout stream will be inundated by a reservoir, the pH will be far beyond the lethal level) is typically much easier than establishing that some percentage reduction in abundance has occurred or will occur. This difference in implications for the assessment and decision-making processes justifies treating extirpation and abundance as different endpoints.

Text Box 3. Overlap of GEAEs

GEAEs are not necessarily discrete or mutually exclusive; therefore, a set of GEAEs may have some redundancy. For example, the condition of an ecological entity at one level of biological organization (e.g., organism) may influence the condition of other entities at that level, as well as interdependent entities at higher levels of organization (e.g., population, community).

Also, a large change in one attribute may overlap with another attribute, as in the case of abundance and extirpation. Furthermore, GEAEs may relate to more than one of the environmental value categories, discussed in Appendix B, which may be reflected in multiple statutes, regulations, public policies or public input that shape an ERA.

Similarly, a kill of organisms has short-term effects on population abundance but does not necessarily have a significant or long-term effect on abundance. The methods for determining that a kill has occurred are much simpler than the methods for determining that the abundance of a population has changed. In addition, the effects on the public of a kill, such as concerns about odor and disease, are not necessarily related to effects on the populations involved. For example, public response to a fish kill may not be related to the ability of the fish populations involved to recover rapidly. Therefore, kills are distinct from both population abundance and extirpation in terms of assessment approaches and management implications.

Table 2-1. Conventional Generic Ecological Assessment Endpoints (C-GEAEs)

Entity	Attribute	Identified EPA Precedent(s)
Organism-Level Endpoints		
Organisms (in an assessment population or community)	Kills (mass mortality, conspicuous mortality)	Vertebrates
	Gross anomalies	Vertebrates Shellfish Plants
	Survival, fecundity, growth	Endangered species Migratory birds Marine mammals Bald and golden eagles Vertebrates Invertebrates Plants
Population-Level Endpoints		
Assessment population	Extirpation	Vertebrates
	Abundance	Vertebrates Shellfish
	Production	Vertebrates (game/resource species) Plants (harvested species)
Community- and Ecosystem-Level Endpoints		
Assessment communities, assemblages and ecosystems	Taxa richness	Aquatic communities Coral reefs
	Abundance	Aquatic communities
	Production	Plant assemblages
	Area	Wetlands Coral reefs Endangered/rare ecosystems
	Function	Wetlands
	Physical structure	Aquatic ecosystems
Officially Designated Endpoints		
Critical habitat for threatened or endangered species	Area	No EPA precedent identified
	Quality	
Special places	Ecological properties that relate to the special or legally protected status	National parks National wildlife refuges The Great Lakes National marine sanctuaries National estuaries

Table 2-1. Conventional Generic Ecological Assessment Endpoints (C-GEAEs)

Entity	Attribute	Identified EPA Precedent(s)

Note: GEAEs for which EPA has identified existing policies and precedents, in particular the specific entities listed in the third column, are included in this table.

Table 2-2. Policy Support for and Practicality of the C-GEAEs

C-GEAE	Entity: Attribute	Policy Support	Practicality
Organism-Level Endpoints			
1	Organisms: kills (mass mortality, conspicuous mortality)	Supported by many EPA programs (e.g., incidents of bird mortality have influenced decisions to restrict the use of pesticides such as diazinon and carbofuran).	Likelihood of kills from chemical pollutants can be estimated from toxicity testing and incidents may be observed and reported.
2	Organisms: gross anomalies	Gross anomalies in birds, fish, shellfish and other organisms are a cause for public concern and have been the basis for EPA regulatory action and guidance (e.g., assessed at Superfund sites, incorporated into biocriteria for water programs).	External gross anomalies are readily observed and are commonly included in survey protocols for fish, corals and forests. They also are reported in toxicity tests of fish, birds, mammals and plants.
3	Organisms: survival, fecundity, growth	Many EPA programs rely on organism-level attributes of survival, fecundity and growth in assessing ecological risks (e.g., water quality criteria, pesticide and toxic chemical reviews, Superfund sites). Organism-level species protection is mandated by the ESA, Marine Mammal Protection Act,[5] Bald and Golden Eagle Protection Act[6] and Migratory Bird Treaty Act.[7]	Results of toxicity tests of the survival, fecundity and growth of organisms are abundant and often can be extrapolated to endangered species and other species of concern. Information on the ranges of listed endangered species is available through state and federal governments.
Population-Level Endpoints			
4	Assessment population: extirpation	EPA has taken action or provided guidance to prevent extirpation of local populations (e.g., assessment of likelihood of extirpation of fish populations because of acid rain). See also the description for Assessment population: abundance.	Extirpation can be predicted using population viability analysis. Demonstrating extirpation may be easy or difficult, depending on the conspicuousness of a species. See also the description for Assessment population: abundance.

[5] Marine Mammal Protection Act of 1972, 16 U.S.C. § 1361–1407 (1972).

[6] Bald and Golden Eagle Protection Act of 1940, 16 U.S.C. § 668–668d (1940).

[7] Migratory Bird Treaty Act of 1918, 16 U.S.C. § 703–712 (1918).

Table 2-2. Policy Support for and Practicality of the C-GEAEs (cont.)

C-GEAE	Entity: Attribute	Policy Support	Practicality
Population-Level Endpoints (cont.)			
5	Assessment population: <u>abundance</u>	Major environmental statutes mandate protection of animals, plants, aquatic life and living things generally, which can be inferred to entail protection of populations. EPA policies for pesticides, toxic chemicals, hazardous wastes and air and water pollutants are intended to protect assessment populations of organisms. Mammals, birds, fish, aquatic invertebrates and plants are typically assessed.	Changes in abundance may be predicted using conventional toxicity data with statistical extrapolation models and population models (e.g., EPA's Office of Pollution Prevention and Toxics evaluated a population model to explore effects of chloroparaffins on fish populations). Measurement of abundance in the field may be easy or difficult, depending on the species.
6	Assessment population: <u>production</u>	See description for Assessment population: abundance. Additionally, several laws are intended to maintain production of various economically valuable species. EPA water programs (e.g., National Estuary Program) and air programs (e.g., criteria pollutant standards) have involved protecting production of resource species populations.	Changes in production may be predicted using conventional toxicity data, as well as population-based approaches. For resource species such as tree or fish species, production changes may be measurable in the field but may require long periods of observation.
Community- and Ecosystem-Level Endpoints			
7	Assessment communities, assemblages and ecosystems: <u>taxa richness</u>	EPA water quality biocriteria frequently incorporate measures of community taxa richness. Additionally, EPA testing for pesticides, toxic chemicals and water pollutants is intended to assess impacts to communities, as well as populations and organisms. Fish, aquatic invertebrates and aquatic plant assemblages often are assessed.	Changes in communities can be inferred or modeled from conventional toxicity data. Measuring taxa richness and abundance of aquatic communities, at least for fish and macroinvertebrate communities, is practical and well established. Ecosystem models that assess effects of toxicants on community properties are available and can use data acquired from organism-level laboratory testing, but to date, they have not been applied routinely.
8	Assessment communities, assemblages and ecosystems: <u>abundance</u>	As in the case of taxa richness, water quality biocriteria incorporate measures of community abundance, and EPA testing protocols are intended to assess impacts to communities.	See description above for taxa richness within assessment communities.

Table 2-2. Policy Support for and Practicality of the C-GEAEs (cont.)

C-GEAE	Entity: Attribute	Policy Support	Practicality
Community- and Ecosystem-Level Endpoints (cont.)			
9	Assessment communities, assemblages and ecosystems: production	EPA water quality policies address overproduction of aquatic plants (and concomitant eutrophication) due to excess input of nutrients. EPA policies for pesticides, toxic chemicals, water pollutants and air pollutants (as in the case of ozone and acid rain) also target decreases in production of forests or other plant communities.	Methods for measuring plant production are well developed for both terrestrial and aquatic communities. Methods for predicting effects of nutrient addition are relatively well developed. Protocols for testing plant toxicity are available and include production metrics.
10	Assessment communities, assemblages and ecosystems: area	Policy support exists for considering the area of wetlands, coral reefs and endangered/rare ecosystems. Among the support for wetland protection are the Clean Water Act (CWA),[8] the National Environmental Policy Act (NEPA),[9] the Coastal Zone Management Act,[10] Executive Order 11990 (Carter 1977) and the federal wetlands delineation manual (Environmental Laboratory 1987). Policies for protection of coral reefs are established by Executive Order 13089 (Clinton 1998); additional support may be found in the Coastal Zone Management Act[10] and the Marine Protection, Research, and Sanctuaries Act.[11] Many U.S. coral reefs are protected by state or federal government. Fewer EPA precedents exist for endangered/rare ecosystems, but a variety of EPA programs have considered them (e.g., Superfund, NEPA).	Assessing the area of communities is generally straightforward, although when clear boundaries between communities are absent, defining areas may be somewhat difficult. Methods for delineating wetlands are well established, and changes in wetland area are therefore relatively straightforward to measure and monitor over time. The area of coral reefs also is relatively straightforward to determine. Prediction of change from one community or ecosystem type to another may be difficult.

[8] Clean Water Act of 1972, 33 U.S.C. § 1251 et seq.

[9] National Environmental Policy Act of 1969, 42 U.S.C. § 4321 et seq.

[10] Coastal Zone Management Act of 1972, 16 U.S.C. § 1451 (1972).

[11] Marine Protection, Research, and Sanctuaries Act of 1972, 33 U.S.C. § 1401–1445, 16 U.S.C. § 1431–1447f, 33 U.S.C. § 2801–2805 (1972).

Table 2-2. Policy Support for and Practicality of the C-GEAEs (cont.)

C-GEAE	Entity: Attribute	Policy Support	Practicality
Community- and Ecosystem-Level Endpoints (cont.)			
11	Assessment communities, assemblages and ecosystems: function	Policy support for ecosystem function is primarily limited to wetlands. The support for wetland protection cited above for community/ecosystem area generally applies to wetland function as well.	Loss of wetland function can be inferred from loss of wetland area. Losses of function independent of area loss, however, generally are not readily observable or predictable.
12	Assessment communities, assemblages and ecosystems: physical structure	The primary policy support for this endpoint derives from the CWA,[8] which applies to aquatic ecosystems. Restoring and maintaining the physical integrity (along with the chemical and biological integrity) of the nation's waters is the primary goal of the CWA. EPA policies and monitoring guidance under the Act include measures of physical structure.	Protocols exist for measuring many of the physical characteristics of aquatic ecosystems. The impacts of many actions (e.g., channelization, dam construction) on the physical structure of water bodies can be readily predicted. Other effects (such as hydrology changes that are a result of land use changes) are more difficult, but still possible, to model.
Officially Designated Endpoints			
13	Critical habitat for threatened and endangered species: area	The ESA[1] specifically mandates the protection of critical habitat for endangered species in addition to the species themselves. The area (quantity) of available habitat is commonly used in assessing risks to these species.	Information on habitat used by listed species is available from state and federal agencies, although critical habitat has not been officially designated for most listed species. Generally, determining effects on habitat area is practical.
14	Critical habitat for threatened and endangered species: quality	Legal protection of critical habitat extends to the quality (suitability) of the habitat to endangered species, in addition to its extent.	Assuming that critical habitat can be identified (even if not officially designated), determining whether it has been or will be adversely modified generally should be practical.
15	Special places: ecological properties that make them special or legally protected	The CAA,[3] NEPA[9] and other statutes require protection of special places such as national parks, wilderness areas and wildlife refuges; this is reflected in EPA policies. The CWA[8] affords EPA a role in designating national estuaries and outstanding national resource waters, which receive additional protection.	Special places and their important ecological properties usually can be defined readily. The ability to predict or detect impacts on these properties will depend on the nature of the properties and whether impacts are direct or indirect.

Note: See Appendix A for details and additional references.

2.1. Definitions of C-GEAE Entities and Attributes

Organisms. Organisms are the most distinct units of ecology, and attributes of organisms have been the focus of EPA's efforts to protect the environment. The use of organisms as endpoints, however, does not imply that each individual is protected. Rather, "organisms" is a level of biological organization with certain attributes that may be the basis of management decisions. Although organisms of any species may be chosen as assessment endpoint entities, some species are protected at the organism level by statute, including (1) endangered and threatened species (i.e., those listed by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service as in danger of extinction under the ESA);[1] (2) marine mammals that are protected by the Marine Mammal Protection Act (i.e., whales and porpoises, seals, sea lions, walruses, polar bears, sea otters, manatees);[5] (3) bald eagles and golden eagles, which are protected by the Bald and Golden Eagle Protection Act;[6] and (4) nearly all birds in the United States, including their eggs and nests, which are protected by the Migratory Bird Treaty Act.[7]

1. **Kills:** *an event or multiple events involving deaths of numerous organisms within an assessment population or community.* Kills also may be referred to as mass mortality or conspicuous mortality. These events may be repeated and widespread, as in bird kills resulting from pesticide applications; repeated at a location, as in fish kills resulting from repeated water treatment failures; or a single event, as in a seabird kill resulting from an oil spill. They may involve one or more species. Precedents for this GEAE have involved vertebrates.

2. **Gross anomalies:** *deformities, lesions or tumors in animals; death or necrosis of plant leaves; or other overt physical injuries of organisms within an assessment population or community.* The occurrence of these injuries may involve one or more species. Precedents for this GEAE have involved vertebrates, shellfish and terrestrial plants.

3. **Survival, fecundity or growth:** *survival (which may be reduced by direct lethality or by sublethal effects that diminish survival probabilities); fecundity (i.e., the production of viable young); or growth (i.e., increased mass or length) of some proportion of the animals or plants in an assessment population or community.* These are the basic attributes of concern for nonhuman organisms. In addition to the specific legal protections at the organism level for the groups discussed above, precedents exist for using these attributes for vertebrates, invertebrates and plants.

Assessment population. An assessment population is a group of conspecific organisms occupying an area that has been defined as relevant to an ERA.

4. **Extirpation:** *depletion of an assessment population to the point that it is no longer a viable resource or is unlikely to fulfill its function in the ecosystem.* Precedents for this GEAE have involved vertebrates and benthic invertebrates.

5. **Abundance:** *number or density of individuals in an assessment population.* Total abundance or abundances by age or size classes may be used. Precedents have involved vertebrates and shellfish.

6. **Production:** *the generation of biomass or individuals in an assessment population resulting from survival, fecundity or growth.* Precedents have involved vertebrates (primarily game and resource species) and plants (primarily harvested species).

Assessment community, assemblage or ecosystem. An assessment community is a multispecies group of organisms occupying an area that has been defined as relevant to an ERA. Groups that are limited to organisms in a taxon (a plant community or bird community) or that are in certain size classes within a taxon (macroinvertebrates or zooplankton) are termed assemblages. Ecosystems are equivalent to communities but include the physical and chemical features of the environment.

7. Taxa Richness: *the number of native species or other taxa in an assessment community or assemblage.* Precedents have involved aquatic communities and policies protecting coral reefs.

8. Abundance: *the number of individuals in an assessment community or assemblage.* Total abundance or relative abundances of individual species, other taxa, trophic groups or other ecologically defined groups may be used. Precedents have involved aquatic communities.

9. Production: *the generation of biomass or individuals in an assessment community or assemblage.* Precedents for this GEAE have involved plant assemblages. The assemblage may include all plants in an area or a water body, in a taxon (e.g., flowering plants) or in another definition (e.g., phytoplankton, herbaceous plants).

10. Area: *the extent of a particular type (e.g., Atlantic white cedar bog) or category (e.g., palustrine wetlands) of ecosystem.* Area is a protected attribute of wetlands and coral reefs. Precedents exist for protecting the areal extent of rare or endangered ecosystem types, which are ecosystems that are at high risk of extinction because they are rare or significantly declining because of destruction or transformation to another type. The ecosystem may be generic (e.g., old growth or virgin forests in the conterminous United States) or geographically specific (e.g., Hempstead Plains grasslands on Long Island, NY). The U.S. Geological Survey and NatureServe (http://www.natureserve.org/), among others, have compiled information on rare ecosystem types.

11. Function: *processes performed by ecosystems that are services to humans or other ecological entities.* Function is a protected attribute of wetlands. Functional attributes of wetlands may include water storage, maintenance of high water tables, nutrient retention and cycling, sediment retention, accumulation of organic matter and maintenance of habitats for wetland-dependent plants and animals.

12. Physical structure: *the physical attributes or characteristics of water bodies, including hydrological characteristics, bathymetry, bank form, sinuosity, pool and riffle structure, bank and channel vegetation and substrate type and composition.* Precedents are limited to aquatic ecosystems. This endpoint includes the esthetic and other values of aquatic ecosystem structure, not simply habitat quality for aquatic organisms.

Critical habitat for threatened and endangered species. Critical habitat is the specific area within the geographical area occupied by an endangered or threatened species in which are found physical or biological features essential to the conservation of the species and that may require special management considerations and protections (16 U.S.C. § 1532(5)). Critical habitats are legally defined, specified and listed by the U.S. Secretary of Interior (50 CFR Chapter 1, Subpart I, Sections 17.94–96). Habitats that are critical to a threatened or endangered species should be protected when identified, however, even if they are not listed.

13. Area: *the land coverage or equivalent aquatic extent (e.g., stream kilometers) that potentially supports the endangered or threatened species*.

14. Quality: *the suitability of the habitat to support the endangered or threatened species*.

Properties of Special Places: Special places are public and private areas of ecological or cultural significance that are not necessarily endangered or threatened but for which the unique character or natural heritage is important—as revealed by laws or other actions that set them aside. Examples include world heritage sites, national parks and natural landmarks, wilderness areas, national wildlife refuges, national conservation areas, wild and scenic rivers, estuarine and marine sanctuaries, private nature preserves (e.g., Nature Conservancy preserves, National Audubon Society sanctuaries) and state and local parks. For a more comprehensive list, see EPA's *Targeting Priority Natural Resource Areas* (U.S. EPA 1991b).

15. Ecological properties: *properties to be protected are those that make a place special or legally protected.* These include those properties that are an important part of the historical or cultural heritage of a place (e.g., shortgrass prairie at Little Bighorn National Monument). Hence, this GEAE is relevant only to special places with ecological properties that are important to their designation. EPA would not, for example, apply this GEAE to a renovation of Grant's Tomb.

2.2. Assessment Populations and Communities

Because the conventional ecological meaning of "populations" and "communities" presents problems in practice, this document introduces the terms "assessment population" and "assessment community" (defined above). Although ecological assessment endpoints include population properties, such as abundance and production, and community properties such as species richness, delineating populations and communities in the field is difficult. Classically defined populations are discrete and interbreeding. Classically defined communities are discrete, and their constituent species are relatively consistent and interact in predictable ways. Although these classical definitions have been important to the development of genetics, evolution and ecology (e.g., Hardy-Weinberg equilibrium, the competitive exclusion principle), they always have had manifest limitations in practice.

More recently, ecology has become more focused on temporal dynamics, spatial patterns and processes and stochasticity that belie the notion of static, independent populations. One example is metapopulation analysis, which reveals that population dynamics are significantly determined by the exchange of individuals among habitat patches or differential movement across a landscape that continuously varies in suitability (Hanski 1999). Communities are subject to the same dynamics. For example, the species diversity of Pacific coral reefs apparently is determined by the availability of recruits from other reefs within 600 km (Bellwood and Hughes 2001). If the composition of coral reefs, which would appear to be classic discrete communities, is in fact determined by regional dynamics, the chance of delimiting discrete communities in general is small.

Populations may be delimited readily if they are physically isolated within a broader species range (e.g., a sunfish population in a farm pond) or if the species consists of only one spatially discrete population (e.g., the endangered Florida panther, whose current range is restricted almost exclusively to southwestern Florida). Otherwise, population boundaries are difficult to define because they are typically structured on multiple scales. Genetic analyses, which are needed to define discontinuities in interbreeding frequencies and thus to delimit populations, are not a practical option for most ERAs.

The practical problems are even greater for communities. Although the members of a population consist of a single species, whether a particular group of organisms constitutes an instance of a particular community type is not always clear. This is because the species composition of communities varies over space and time.

To protect properties such as population production or community species richness, developing a pragmatic solution to these problems is necessary. An example of such a solution is the approach taken by the Nature Conservancy and NatureServe to inventory and map biodiversity (Stein et al. 2000). Because defining discrete populations or communities is not feasible, these organizations inventory and map occurrences of conservation elements, which may be defined at various scales, depending on the elements and circumstances. For example, a plant community occurrence may be "a stand or patch, or a cluster of stands or patches." An occurrence of a bird species, however, would be defined quite differently.

This document proposes a similar approach for assessment endpoints. For individual assessments, the population or community entities to be protected are defined during the problem formulation stage of risk assessment. These assessment populations and assessment communities should be defined in a way that is biologically reasonable, supportive of the decision and pragmatic with respect to policy and legal considerations. For example, defining the belted kingfishers in a 20-m stream reach as an assessment population would not be reasonable if that reach cannot fully support one belted kingfisher pair. On the other hand, although the kingfisher's range is effectively continuous, defining the entire species as the assessment population would not be reasonable, given that it ranges across nearly all of North America. Rather, defining the kingfishers on a watershed or a lake as an assessment population may be reasonable.

Assessment populations also may be defined by nonbiological considerations. For example, for Superfund ERAs on the U.S. Department of Energy's Oak Ridge Reservation, populations of large terrestrial vertebrates were delimited by the borders of the reservation (Suter et al. 1994). This definition was reasonable not only because the Superfund site was defined as the entire reservation, but also because the reservation was large enough to sustain viable populations of deer, wild turkey, bobcat and other large terrestrial vertebrates. Although the reservation is more forested than are the surrounding agricultural and residential lands, its borders are not impenetrable and are not ecologically distinct at all points. The pragmatic definition proved useful, however, and acceptable to the parties. For similarly practical reasons, one might define an assessment community of benthic invertebrates in the first fully mixed reach of a stream receiving an effluent.

The selection of a scale to define an assessment population or community involves a tradeoff. If the area is large relative to the extent of the stressor, the effects of that stressor will be diluted. If the area is small, however, the assessment population or community may be affected significantly but may seem too insignificant to prompt stakeholder concern or action by the decision maker. Therefore, appropriate spatial scales should be determined during the problem formulation stage for individual risk assessments, taking into consideration both the ecological and policy aspects of the problem; they should not be manipulated during the analysis to achieve a desired result.

3. GENERIC ECOSYSTEM SERVICES ENDPOINTS (ES-GEAEs)

This chapter presents an initial set of ES-GEAEs. Ecosystem services are defined as the outputs of ecological processes that contribute to human welfare or have the potential to do so in the future (U.S. EPA 2006; U.S. EPA 2016). Ecosystem services include the production of food and drinking water, purification of air and water, pollination and nutrient cycling. The need to protect the services provided by natural systems has been previously recognized (e.g., Daily et al. 1997; Daly 1997), but ecosystem services have not been formally incorporated into ERA practice. EPA (2016) describes the ecosystem services concept in detail and provides the technical basis for the development of ES-GEAEs presented here.

Table 3-1 presents ES-GEAEs organized by the environmental values to be protected, including consumptive, informational, functional/structural, recreational, option and existence values. The entities to be protected are generally consistent with levels of biological organization presented in Table 2-1 for C-GEAEs. Unlike C-GEAE attributes such as mortality, abundance and production, however, ecosystem services attributes are cast in terms of the ecological outputs that directly or indirectly benefit humans. The last column in Table 3-1 presents examples of ecosystem services endpoints that could be derived for specific assessments from ES-GEAEs.

The use of ecosystem services endpoints is a conceptual and analytical step beyond the use of conventional endpoints. Conventional endpoints are derived directly from the state of the ecosystem (e.g., biophysical structure and function). Ecosystem services endpoints are derived from those same ecosystem states but are reinterpreted in terms of services to humans based on the economic, health and psychosocial benefits that they can provide. For example, the measured or modeled ecosystem process, net primary production of Douglas fir, corresponds to the conventional assessment endpoint, forest production, which can be translated into the ecosystems services endpoint, timber production.

ES-GEAEs are intended to complement C-GEAEs by extending assessment endpoints to services that benefit humans and may be economically valued and demanded by humans (see Section 1.5). The services encompass both use and nonuse values and options for future generations (Table 3-1). The adoption of ecosystem services as a type of assessment endpoint is intended to improve the value of ERA to environmental decision making. For example, if the results of an ERA are expressed as losses or gains of ecosystem services, those results can be more directly useful to an economist who assesses the costs and benefits of protection or remediation (U.S. EPA 2016). Application of ES-GEAEs in an assessment can provide an improved means of communicating risks and informing management decisions because incremental changes in the endpoints directly or indirectly benefit humans (e.g., Forbes and Calow 2012).

Table 3-1. Generic Ecosystem Services Assessment Endpoints (ES-GEAEs)

Environmental Value Category	Entity	Attribute	Example Ecosystem Services Endpoint
Consumptive: value of commodities produced by environment	Forest ecosystem	Timber and fuel production	Mass of wood produced
	Ground water Surface water	Clean water production	Volume of drinking water provided
	Natural ecosystem	Food production	Quantity and quality of food produced
	Agricultural ecosystem	Fiber and food production	Quantity of fiber produced

Table 3-1. ES-GEAEs (cont.)

Environmental Value Category	Entity	Attribute	Example Ecosystem Services Endpoint
Consumptive: value of commodities produced by environment (cont.)	Ecosystem	Raw materials/natural products supplied	Number of natural products produced
Informational: value of environment as a source of traits or models for anthropogenic breeds, structures, chemicals and processes	Species	Providing novel molecules and biophysical structures	Number of novel chemical or physical structures identified
	Species	Genetic resources	Number of new genetic materials provided
Functional/Structural: value of ecological functions and structures	Ecosystem	Climate regulation	Quantity of carbon sequestered
	Watershed	Water regulation	Volume of ground water recharged
	Ecosystem	Water/air/soil purification	Mass of contaminant removed
	Ecosystem	Waste treatment	Quantity of waste treated
	Terrestrial plant community	Erosion regulation	Quantity of soil loss prevented
	Ecosystem	Natural hazard regulation	Extent of flooding avoided
	Pollinators/Seed dispersers	Pollination Seed dispersal	Areal extent of crops pollinated
	Ecosystem	Nutrient cycling	Amount of nitrogen fixed, denitrified or sequestered
	Terrestrial ecosystem	Soil formation/fertility	Quantity of top soil created
	Ecosystem	Pest/Disease control	Number of crop pests eliminated
Recreational: value of recreational opportunities	Ecosystem	Ecological attributes favorable to recreation/tourism*	Number of visitor-day opportunities
Educational: value of educational opportunities	Organisms, population, community, ecosystem	Ecological attributes favorable to education/cognitive development*	Number of visitor-day opportunities

Table 3-1. ES-GEAEs (cont.)

Environmental Value Category	Entity	Attribute	Example Ecosystem Services Endpoint
Option: value to future generations from environmental preservation	Ecosystem	Attributes that could be provided to future generations	Quantity available in the future
Existence: nonuse value of environment	Organisms, population, community, ecosystem	Ecological attributes favorable to cultural enrichment†	Cultural significance†

Note: For details on environmental value categories, see Appendix B. Attributes are adapted from MEA (2005) and de Groot et al. (2002), unless otherwise noted.
*See Costanza et al. (1997).
†Spiritual/inspirational/esthetic value.

4. HOW TO USE THE GEAEs

In a risk assessment for a specific site, effluent, stressor or action, determining whether any of the GEAEs are applicable to the assessment and sufficient for the case is necessary, and if so, how they can be made specific to the case. These activities are performed as part of the problem formulation phase of the risk assessment (U.S. EPA 1998a).

> **Text Box 4. Criteria for Selection of Assessment Endpoints**
>
> EPA has provided criteria for developing assessment-specific endpoints: ecological relevance, susceptibility and relevance to management goals (U.S. EPA 1998a, Section 3.3.2). Additionally, ecosystem services endpoints also must have attributes of value to humans.
>
> **Ecological relevance** pertains to the role of the endpoint entity in the ecosystem and, therefore, depends on the ecological context.
>
> **Susceptibility** pertains to the sensitivity of the endpoint to the stressor relative to its potential exposure and, therefore, depends on the identity of the stressor and the mode of exposure.
>
> **Relevance to management goals** pertains to the goals set by the decision makers and, therefore, depends on the societal, legal and regulatory context of the decision, as well as the preferences of the individual decision maker and stakeholders.
>
> These situation-specific criteria should be applied whenever GEAEs are converted to assessment endpoints in individual assessments.

4.1. Using GEAEs in Assessment Endpoint Selection

The sets of C-GEAEs and ES-GEAEs are intended to be helpful for identifying and specifically defining assessment endpoints for particular assessments. During problem formulation, risk assessors, scientists, risk managers and stakeholders identify endpoints that are relevant to the assessment, potentially are of sufficient importance to influence the decision, and reflect any goals that may have been set prior to the problem formulation (U.S. EPA 1998a). The assessment-specific criteria for selecting assessment endpoints from the guidelines for ERA are used in that process (Text Box 4).

The process of developing assessment endpoints for an ERA may be thought of as bringing together five types of information and answering questions related to each, as detailed below. Together, the questions address the criteria for ecological assessment endpoints. The GEAEs constitute one type of information that answers Question 5. In addition, the tables of GEAEs (Table 2-1 and Table 3-1) can be consulted while answering the other questions as a means of ensuring that the common types of entities and attributes are considered.

1. **Stressor characteristics.** *What is susceptible to the stressor?* For well-understood stressors, this question is straightforward. For example, benthic invertebrates are susceptible to dredging, birds are susceptible to granular pesticides and wetlands are susceptible to filling.

2. **Ecosystem and receptor characteristics.** *What is present and ecologically relevant?* For site-specific assessments, these are the species, communities or ecosystems at the site. For other assessments, the scenario should define the types of species, communities and ecosystems that are likely to be exposed. For example, an assessment of a new pesticide for corn would consider the species likely to be found in or adjacent to corn fields in the midwestern United States. In the absence of specific information about the particular importance of an entity, those that are present may be assumed to be ecologically relevant.

3. **Management goals.** *What is ecologically relevant to the management goals?* Statements of management goals should suggest the changes in attributes of ecological entities that would preclude achieving the goal.

4. **Input by interested parties.** *What ecological issues are of concern?* If interested parties are consulted or make their preferences known, their concerns about particular ecological effects should be considered. Although societal values at a national scale are reflected in the GEAEs, values that are specific to a locale or resource are expressed by interested parties.

5. **GEAEs and policies or precedents.** *What is supported by policy or precedent?* The C-GEAEs defined in this document provide a set of entities and attributes that meet this criterion, by representing national goals and policies at the time of publication. The ES-GEAEs have the potential to supplement the C-GEAEs in supporting national goals and policies.

The answers to each of these questions would be a list of potential assessment-specific endpoints. None of the questions imply absolute requirements. For example, susceptibility to a novel stressor may be unknown, and the concerns of interested parties often are unknown and often do not include important potential endpoints.

No particular procedure is prescribed for this process of answering the questions or for using the GEAE set. If consistency with policy and precedent is particularly important, one might go through the C-GEAE set and ask the other four questions with respect to each generic endpoint. Alternatively, the questions might each be answered and the lists then integrated. In that case, the endpoints for a specific assessment simply may be those that are represented on most of the lists.

4.2. Making the Generic Endpoints Specific

To convert a GEAE into an assessment endpoint for a specific assessment, defining the specific entity and attribute and the spatial and temporal context of the entity is necessary. This specificity is needed to make the endpoint relevant to the assessment and to determine which measurements and models are needed to estimate it (Figure 4-1).

Consider the first C-GEAE, kills of organisms, as an example. For a specific assessment endpoint, assessors must specify whether the endpoint entity corresponds to members of a specific taxon such as fish or birds, an assemblage such as macroinvertebrates or a specific species such as sea otters. The generic attribute is kills, which should be defined more specifically and in terms that are appropriate to the assessment. For example, the definition of a kill would differ for a well-monitored experimental use of a pesticide versus public reports of mortalities, oil spills versus lawn treatments and modeling studies versus observational studies. Definitions could include the number of organisms that must die for an episode to be considered a kill, the proportion of organisms visiting a site that would be expected to die or the frequency of public reports of dead organisms associated with the stressor. Finally, the spatial and temporal contexts should be defined. For an effluent, the contexts may be the downstream reach within which mixing occurs and the period of a permit. For a pesticide, the context may be the region within which the pesticide is used on a particular crop and the number of applications per year over the period of use. For an oil spill, the context may refer to the area encompassed by the plume and the time until the plume is dispersed or degraded to the point that it no longer oils marine birds or mammals. Thus, an assessment endpoint derived from this GEAE (kills of organisms) might be episodic mortality of at least 10 fish of any species occurring in the 1-km reach downstream of the effluent release point.

The answers to the first four of the five questions in Section 4.1 provide the basis for specific endpoint definitions; that is, they determine which specific organisms, populations or ecosystems are susceptible and potentially exposed and which are of concern; the spatial and temporal scales that are relevant to management goals; and other relevant considerations.

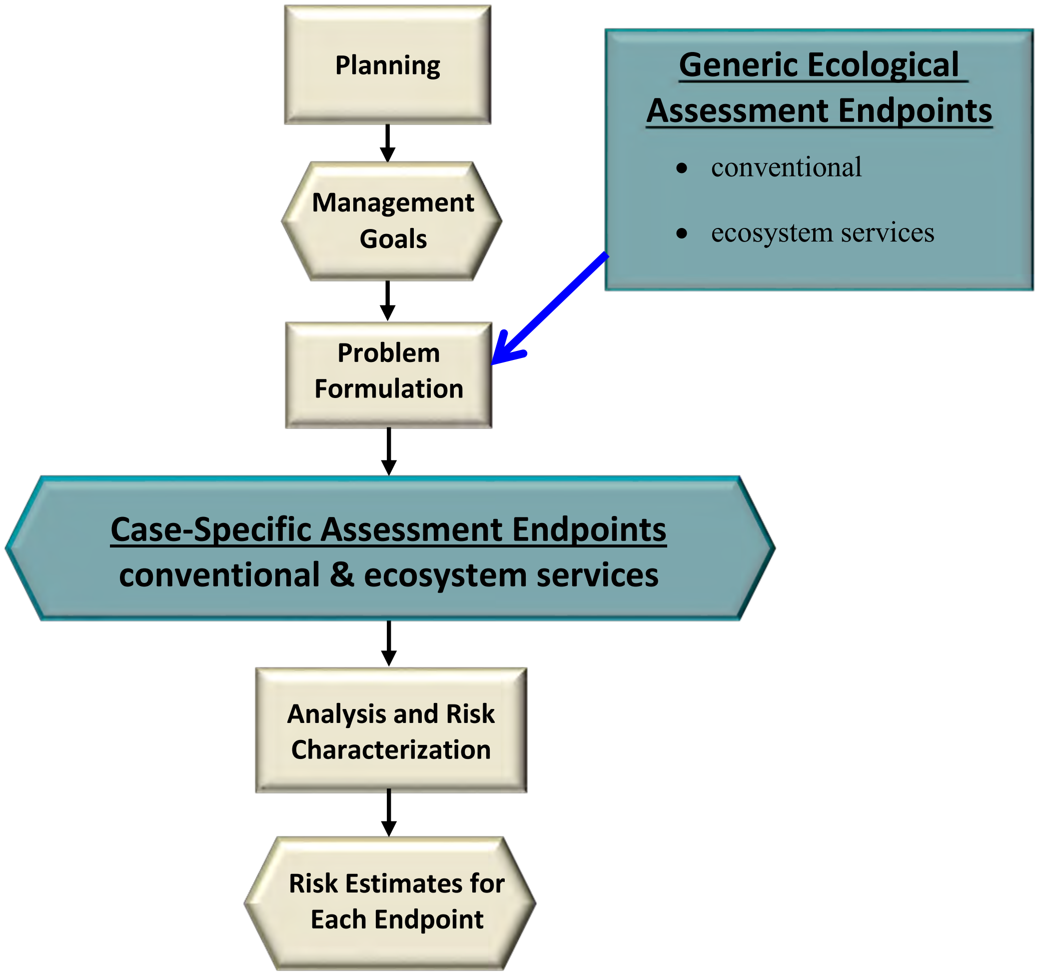

Figure 4-1. Steps for Incorporating Generic and Case-Specific Assessment Endpoints in the ERA Process

More than one assessment endpoint may be derived from a GEAE for a particular assessment. For example, the C-GEAE of population abundance may be used to generate assessment endpoints for each of several populations of concern, and the change in abundance and spatial context may differ for each. On the other hand, a site-specific concern may relate to more than one GEAE. If, for example, the entity is a wetland, site-specific problem formulation must determine whether the management goals and the evidence of wetland susceptibility are related to the area of the wetland, a functional attribute of the wetlands such as nitrogen retention or both.

4.3. Other Conventional Ecological Assessment Endpoints

The C-GEAEs presented in this document are those that EPA currently believes to be generically useful and do not preclude the use of other endpoints. Other endpoints may be chosen because they reflect some particular environmental value associated with a site or held by a particular stakeholder, or for some other reason that makes them particularly appropriate for a given assessment (see Section 4.1). In addition, some endpoints that are not generically practical may be practical in a particular case because of peculiarities of the stressor or receptor; or because of the availability of data, a model of the receiving system or time and resources to assess a difficult endpoint. These additional assessment endpoints must meet the criteria in EPA's ERA guidelines.

4.4. Using ES-GEAEs

Like C-GEAEs, the ES-GEAEs are used to assist in endpoint selection for assessments, which can be done in two ways. First, during problem formulation, the participants may identify the ecosystem services provided by the conventional endpoint entities that they have chosen. Second, ecosystem services endpoints may be identified independently of any relationship to conventional endpoints. The first approach has the advantage that the conventional endpoints already have been determined to be relevant, susceptible and otherwise appropriate to the assessment. The second approach has the potential advantage of identifying important services that are at risk but are not related directly to a selected conventional endpoint. Because the identification of ES-GEAEs involves additional inferential steps, the use of these endpoints increases the need for rigorous problem formulation, including a conceptual model that encompasses the generation of ecosystem services.

As with the C-GEAEs, the ES-GEAEs in Table 3-1 serve as prompts to endpoint development. That is, in the first approach, one might, for each conventional endpoint, move down the table asking whether that endpoint entity provides a service of that type. For example, if a conventional endpoint is hardwood forest productivity, the answer would be yes for timber and fuel production, but no for fiber production. In the second approach, one would move down the table asking whether the stressors being assessed pose a significant risk to services of that type. For example, an insecticide used only on cotton is unlikely to pose a risk to timber production, so that would not be an ecosystem services endpoint.

With either approach, the ecosystem services endpoints should satisfy the general criteria for good assessment endpoints in Text Box 4. Additionally, the services-based endpoint must provide a service to humans. When developing ecosystem services endpoints, considering the five types of information that are relevant to endpoint selection (Section 4.1) would be useful. As stated in that section, the selected entities that perform the service should

1. have attributes that should be susceptible to the stressor.
2. be present or at least potentially present.
3. be relevant to the management goals.
4. reflect the concerns of interested parties.
5. be supported by policy and precedent.

The fifth consideration can be applied now by appealing to this document. That is, generic ecosystem services described in Chapter 3 have been deemed appropriate and potentially useful. The only precedents at the time of publication of this document involve their consideration in reviews of the secondary National Ambient Air Quality Standards (Rea et al. 2012; U.S. EPA 2009a; U.S. EPA 2014). Assessors should track the development of policies and precedents subsequent to this document. This document, in itself, constitutes a step toward the developing such an Agency-wide ecosystem services policy.

A sixth consideration for ecosystem services endpoints is practicality. All of the C-GEAEs are demonstrated to be estimable using available techniques, but that is not necessarily true for all ES-GEAEs. Depending on the case, different degrees of definition and quantification will be required. If ecosystem services are needed to answer questions such as “What are mayflies good for?” a simple listing and description of the services provided by the aquatic community may be sufficient and practical. At the other extreme, a change in ecosystems services that must be quantified and monetized may be impractical for most ecosystem services at the time this document is being written. Even without monetization, the quantitative estimation of changes in ecosystem services presents considerable challenges and additional research and development is needed.

As with C-GEAEs, ES-GEAEs must be made specific to the assessment to become assessment endpoints. For example, in the risk and exposure assessment for the NOx/SOx secondary standard, the chosen conventional assessment endpoint for the terrestrial acidification mode of action was red spruce and sugar maple growth (U.S. EPA 2009a). That endpoint is a specific instance of the C-GEAE: population production. From that specific conventional endpoint, many ecosystem services could be derived from the list in Table 3-1, including food production (e.g., maple syrup), carbon sequestration and provision of opportunities for recreational and esthetic experiences (e.g., viewing fall colors). The various services were described, but the assessment focused specifically on the production of red spruce and sugar maple timber, which could be quantified and monetized.

The ecosystem services construct provides an opportunity to address human well-being quantitatively or qualitatively in decision making. The treatment of ecosystem services should be tailored to the assessment and the decision that it informs. The decision context is critical to determining which ecosystem services would be useful to the decision-making process. In some cases, the qualitative results of the risk assessment, such as a list of goods and services that are jeopardized by the predicted ecological effects, are sufficient to inform a decision. In other cases, quantification and monetization of ecological benefits associated with affected ecosystem services, as well as tradeoffs between alternative decision options, can be helpful. In such cases, ecosystem service assessment endpoints should be selected that are conducive to quantification and monetization, which may require involving social scientists in the endpoint selection process. Ecosystem service assessment endpoints can complement conventional ecological assessment endpoints by clarifying to stakeholders and the public the benefits and costs that a given decision will have on society.

4.5. Completing a List of Assessment Endpoints for a Specific Assessment

When a list of potential assessment endpoints has been developed, reviewing the list and reducing it to those endpoints that are most relevant, susceptible and important to the decision may be necessary. In addition, reducing redundancy in the endpoints may be necessary. For example, kills of organisms imply immediate changes in population abundance that may influence community abundances. If population or community properties are important to the decision maker, they should be retained as endpoints. If kills are sufficient to warrant action, however, the extrapolations to higher levels of biological organization may be unnecessary, and those endpoints may be dropped as redundant. Redundancies between conventional and ecosystem services endpoints are acceptable because they serve different purposes.

The concept of ecosystem services is recommended as a useful supplement to the ERA process to ensure that the impacts and issues associated with human well-being are considered during the risk assessment and decision-making process. Figure 4-1 shows the steps of incorporating both generic and case-specific assessment endpoints into the ERA process.

5. RECOMMENDATIONS

Readers of the first edition of this document were encouraged to (1) develop and maintain a continual, open process for reviewing, amending and creating new GEAEs and (2) establish a means of tracking the many rationales and precedents used for making ecological risk-based decisions throughout EPA. Those recommendations, however, were not implemented. The Technical Panel for this second edition believes that the development and adoption of ecological assessment endpoints is likely to evolve as science advances and policy changes. The generic endpoints will be revisited when justified by an expressed need, such as the call for ecosystem services endpoints that was heard at the most recent Ecological Risk Assessors' Colloquium and initiated the development of this second edition (U.S. EPA 2010).

The Technical Panel continues to encourage ecological risk assessors to consider novel assessment endpoints. EPA is responsible for stating its mandates as clearly understood goals and assessment endpoints for ecological protection. As different stressors challenge the environment and the scientific understanding of ecosystems improves, new ecological assessment endpoints may need to be considered and incorporated into EPA's mission (Text Box 5). Table 5-1 presents potential C-GEAEs recommended by Technical Panel members and reviewers of the first edition for consideration by EPA. Some of these potential assessment endpoints are not entirely new, but rather are extensions of the C-GEAEs listed in Table 2-1, and some do not yet satisfy the criterion of practicality, as defined in Section 1.3. They are intended to inspire the development of novel assessment-specific endpoints and future generic endpoints.

Text Box 5. Developing New Assessment Endpoints

One suggestion for developing new assessment endpoints is to consider the following dimensions associated with ecological systems and whether they are addressed in Agency risk assessment activities:

1. Levels of biological organization (e.g., potentially ranging from DNA to biomes).
2. Spatial scale (e.g., ranging from local to global boundaries).
3. Temporal scale (e.g., considerations of the timing, duration and frequency of biological activities or events).
4. Magnitude (e.g., the total number of ecological entities present, impacted or remaining with respect to a known baseline or presumption of what should be there).
5. Taxonomic groups (i.e., beyond mammals, fish and birds to other taxa such as amphibians, reptiles, invertebrates, bacteria, fungi and flowering and nonflowering plants).
6. Range of ecological properties (e.g., resiliency in ecosystems).

The initial GEAEs presented in Table 2-1 incorporate or touch on many of these dimensions, yet many other assessment endpoints could be derived by increasing the range of just one of these dimensions or by integrating two or more of these dimensions in a new way.

The future of ES-GEAEs is likely to be more dynamic than the history of C-GEAE development, because they are new and not established in policy or practice. If ecosystem services are used as endpoints in EPA's ERAs, the program and regional offices will need to determine which services are relevant to their mandates and how they will be used. The RAF's Ecosystem Services Technical Panel encourages the programs and regions to take that next step.

Table 5-1. Potential New C-GEAEs

Entity	Attribute
Organism-Level Endpoints	
Organisms (in an assessment population or community)	Physiological status (in addition to growth) Disease or debilitation (in addition to gross anomalies) Avoidance behavior Courtship behavior (e.g., birds) Migratory behavior (e.g., birds, salmonids) Nurturing and rearing behavior (e.g., nest abandonment)
Population-Level Endpoints	
Assessment population	Genetic diversity
Community- and Ecosystem-Level Endpoints	
Assessment communities, assemblages and ecosystems	Trophic structure Energy flow Nutrient cycling (in ecosystems in addition to wetlands) Nutrient retention Decomposition rates Sediment and material transport Area or function of estuaries and riparian ecosystems Resilience Vertical structure of plant communities Attributes that influence public health
Landscape-Level Endpoints	
Assessment landscapes (of multiple populations, communities, assemblages and ecosystems)	Spatial pattern (e.g., random, clustered or uniform; dominance; contagion; contiguity or fragmentation; juxtaposition; connectivity)

6. CONCLUSION

The development of this document revealed that the laws, policies and precedents for protecting attributes of ecological entities are numerous and diverse. They provide a strong basis for defining C-GEAEs at the organism, population and community/ecosystem levels of organization.

GEAEs are widely applicable to various assessment scenarios and can provide a foundation for the development of endpoints for specific assessments during problem formulation. The set of C-GEAEs has been used by risk assessors and decision makers with the confidence that they are supported by established policies and precedents and thus will improve the scientific basis for ecological decisions. The set of ES-GEAEs can serve as a starting point for the development and use of ecological assessment endpoints that are more clearly relevant to the anthropocentric concerns of many stakeholders and decision makers.

Risk assessors and decision makers throughout the Agency are encouraged to consider the ecological assessment endpoints that they employ with fresh eyes. Might their decisions be better supported or at least explained more readily to the public if they employed ecosystem services endpoints in addition to conventional endpoints? Time and experience will tell.

APPENDIX A. SUPPORTING INFORMATION

This appendix serves as a reference for those who need to know the basis for a particular conventional generic ecological assessment endpoint (C-GEAE) that is defined in Chapter 2. The C-GEAEs have been divided into three categories of biological organization—organism, population and community/assemblage/ecosystem—as well as a fourth category containing endpoints such as critical habitats and special places that most easily are described separately. Each category is introduced by general information about how the endpoints in that category have been used by the Agency. Additional supporting information, divided into two sections, then is provided for each C-GEAE. The first section is *Laws, Regulations and Precedents*, which discusses the authorities that support the use of each C-GEAE by the U.S. Environmental Protection Agency (EPA) and gives examples of Agency actions that provide a further basis for their use. The second section is *Practicality*, which discusses the availability of methods to estimate risks to the endpoint and their applicability in various risk assessment contexts. Relevant laws, regulations and policies have not changed since the first edition of this document was written in 2003. The potential examples of use and practicality have increased since 2003, but they are not updated here because the examples and practical methods are adequate to justify the C-GEAEs. That this appendix is not intended to be a guide to ecological risk assessment (ERA) methods should be noted.

The specific laws and other policies cited below are not the only support for ecological endpoints. Many federal environmental laws and their implementation provide a general mandate for environmental protection that extends far beyond the specific instances presented in this appendix. In particular, the National Environmental Policy Act (NEPA)[9] encourages federal agencies to protect the environment and prevent its degradation. Although nearly all environmental statutes refer to the environment as an entity to be protected and many refer to more specific ecological entities such as fish, wildlife and estuaries, few indicate an attribute to be protected or even the nature of the entity. In addition, terms are not necessarily used in a technical way. For example, the Clean Water Act (CWA) refers repeatedly to "a balanced indigenous population of fish, shellfish and invertebrates."[8] Clearly, the phrase does not refer to a biological population, which is formed of members of one species. Further, when referring to fish, does the Act mean fish at the level of organism, population or assemblage, or the taxon? Given these ambiguities, the wording of the statutes must be interpreted to define endpoints. The primary source of support for the interpretations presented in this appendix is precedent.

The precedents and other expressions of policy discussed in this appendix are a sample of those that have been used in assessments, guidance, protocols and other Agency actions over the years. Although they are derived from particular laws and regulatory contexts, they may be interpreted broadly as examples of what Congress and the Agency have meant by protecting the environment. For example, the Clean Air Act (CAA) calls for specific protection of "national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value."[3] Although the law is specific to air quality, this requirement might be interpreted broadly as supporting the protection of those special areas from pollution in general, not just from the threats from air pollution that were brought to the attention of Congress.

The following abbreviations and acronyms are used in this Appendix:

CAA	Clean Air Act[3]
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act[12]
C-GEAE	conventional generic ecological assessment endpoint
CITES	Convention on International Trade in Endangered Species[13]
CWA	Clean Water Act[8]
EPA	U.S. Environmental Protection Agency
ERA	ecological risk assessment
ESA	Endangered Species Act[1]
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act[14]
GEAE	generic ecological assessment endpoint
GIS	geographic information system
LC_{50}	median lethal concentration
LD_{50}	median lethal dose
NCP	National Contingency Plan[15]
NEPA	National Environmental Policy Act[9]
OSWER	Office of Solid Waste and Emergency Response
PCB	polychlorinated biphenyl
RCRA	Resource Conservation and Recovery Act[16]
SSD	species sensitivity distribution
TMDL	total maximum daily load
TSCA	Toxic Substances Control Act[17]
USACE	U.S. Army Corps of Engineers

A.1. Organism-Level Endpoints

Major EPA statutes (e.g., CAA, CWA, CERCLA, FIFRA, TSCA, RCRA) require that EPA consider and protect organism-level attributes of various taxa of organisms, including fish, birds and plants; and, more generally, animals, wildlife, aquatic life and living things. The toxicity information that is available to EPA in administering these statutes is dominated by organism-level attributes such as mortality.

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[12] Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. § 9601 et seq.

[13] Convention on International Trade in Endangered Species of Wild Fauna and Flora of 1973, 27 U.S.T. 1087.

[14] Federal Insecticide, Fungicide, and Rodenticide Act of 1996, 7 U.S.C. § 136 et seq.

[15] National Oil and Hazardous Substances Pollution Contingency Plan, 40 CFR Part 300.

[16] Resource Conservation and Recovery Act of 1976, 42 U.S.C. § 6901 et seq.

[17] Toxic Substances Control Act of 1976, 15 U.S.C. § 2601 et seq.

Text Box A.1. Connections between Organism- and Higher-Level Endpoints

Not only are organism attributes potentially important inherently, they also are important because they are protective of higher-level attributes. That is, the common assumption is that if important attributes of organisms in a population or community are protected, the population and community attributes will be protected as well. EPA's principles for ERA at Superfund sites illustrate a common usage of organism-level endpoints at EPA:

> Except at a few very large sites, Superfund ERAs typically do not address effects on entire ecosystems, but rather normally gather effects data on individuals in order to predict or postulate potential effects on local wildlife, fish, invertebrate and plant populations and communities that occur or that could occur in specific habitats at sites…. Levels [of chemicals] that are expected to protect local populations and communities can be estimated by extrapolating from effects on individuals and groups of individuals using a lines-of-evidence approach (U.S. EPA 1999a).

When organism-level information is not sufficient, assessing higher-level attributes directly, by employing population or community models or measurements, may be necessary.

Organism-level attributes tend to be more practical to measure or predict than attributes at higher levels of organization for most EPA assessments. Consequently, EPA's ecological assessments historically have focused on organism-level endpoints (Text Box A.1). Note that these endpoints normally do not imply protection of each individual organism but rather the protection of these critical attributes of organisms within assessment populations or communities (Section 2.2). As will be described, however, certain special categories of organisms, such as endangered species and marine mammals, have been afforded protection on an individual basis.

In ecological assessments, EPA considers organism-level effects in a variety of taxa. For example, tests required for pesticide regulation can include effects on survival, growth and reproduction (C-GEAE #3) of aquatic invertebrates, fish, birds, mammals and terrestrial and aquatic plants. Effects on a similar range of taxa are considered under TSCA (Lynch et al. 1994; Zeeman et al. 1999) and in deriving water quality criteria under the CWA. Less commonly, other taxa (e.g., earthworms at certain Superfund sites, honeybees for certain pesticides, reptiles, amphibians) are considered.

A.1.1. C-GEAE #1. Kills of Organisms

Laws, Regulations and Precedents: Kills

The regulation of chemicals to prevent kills of organisms in the absence of effects on populations or communities has been sustained by federal courts. For example, the use of the pesticide diazinon on golf courses and sod farms was prohibited after documentation of widespread and repeated bird kills (U.S. EPA 1988a). Subsequently, EPA cited continuing bird kills as a factor in the agreement with pesticide manufacturers to phase out all outdoor residential uses of diazinon (U.S. EPA 2001). Bird kills also were the basis for phasing out most uses of another pesticide, granular carbofuran (Houseknecht 1993; U.S. EPA 1991a). Kills of birds and other wildlife in oil pits are considered evidence of "imminent and substantial endangerment to the environment" under RCRA § 7003 (U.S. EPA 2003). Fish kills also have been considered a concern by EPA; for example, Region 5 considers fish kills and other excess mortality to be obvious impacts with respect to their RCRA actions (U.S. EPA 1994).[16]

Under FIFRA reporting requirements for adverse effects of pesticides, EPA categorizes kills (and other adverse incidents) involving multiple organisms as more severe events than single-organism incidents and imposes additional reporting requirements on pesticide registrants for such events. More severe wildlife incidents are defined as those involving at least 1,000 individuals of a schooling fish species or 50 individuals of a nonschooling species, 200 individuals of a flocking bird species, 50 individuals of a songbird species or 5 individuals of a predatory species; or for mammals, reptiles and amphibians, 50 individuals of a relatively common or herding species or 5 individuals of a rare or solitary species (40 CFR Part 159). Incidents involving numbers of organisms below these thresholds still must be reported, but the requirements differ from those for more severe incidents. Also note that these criteria do not apply outside FIFRA.

Practicality: Kills

The likelihood of kills can be estimated using the common acute lethality tests that generate median lethal concentrations or doses (LC50s or LD50s). The number of species involved in kills may be estimated from species sensitivity distributions (SSDs) of LC50s or LD50s, as in the calculation of the acute National Ambient Water Quality Criteria (Posthuma et al. 2002; U.S. EPA 1985a). The occurrence of kills in the field may be observed readily in the cases of conspicuous organisms and open habitats, but in other cases, such as with small birds in crops or fence rows, kills may be unobserved and difficult to document. A model has been developed to predict the probability of bird kills for a particular use of a cholinesterase-inhibiting pesticide using SSDs of LD50s and field studies (Mineau 2002).

A.1.2. C-GEAE #2. Gross Anomalies of Organisms

Laws, Regulations and Precedents: Gross Anomalies

Gross anomalies in birds, fish, shellfish and other organisms are cause for public concern and have been the basis for EPA regulatory action and guidance. For example, crossed bills and other deformities in piscivorous birds are a basis for the proposed remediation of the PCB-contaminated sediments at the Fox River/Green Bay Superfund site (U.S. EPA 1998b; WDNR 2001) and were a basis for the designation of the system as an Area of Concern by the Great Lakes National Program Office (U.S. EPA 2013b). EPA actions to restrict the use of tributyltin as an antifoulant on boats (U.S. EPA 1988b), as well as the restrictions imposed by the Organotin Antifouling Paint Control Act,[18] were triggered by the observed induction of gross deformities in mollusks that threatened the marketability of oysters, reduced the fecundity of the deformed organisms and suggested the potential for other effects.

Natural resource damage regulations for CERCLA,[12] the CWA[8] and the Oil Pollution Act[4] include gross anomalies among the designated injuries (43 CFR § 11.62(f)). Deformities, erosion, lesions and tumors in fish (DELT anomalies) are used in the biocriteria of many state water quality standards and in Agency guidance (U.S. EPA 1996; Yoder and Rankin 1995). Changes in development, which can be manifested in physical anomalies, have been identified as an environmental effect of regulatory concern under TSCA (U.S. EPA 1983).[17]

Anomalies in plants and plant injuries also have been the basis for EPA action. For example, EPA proposed a secondary ambient air quality standard for ground-level ozone partly on the basis of visible foliar injury to commercial crops and natural vegetation, stating that “foliar injury is occurring on native vegetation in national parks, forests, and wilderness areas, and may be degrading the aesthetic quality of the natural landscape, a resource important to public welfare” (U.S. EPA 1997c). EPA also has used visible injury of plants as a basis for regulating air emissions of aluminum reduction plants and sulfuric acid production units (U.S. EPA 1994).

[18] Organotin Antifouling Paint Control Act of 1988, 33 U.S.C. § 2401 (1988).

Practicality: Gross Anomalies

External gross anomalies are readily observed as are some internal anomalies with external manifestations, such as severe scoliosis or large tumors. Gross anomalies commonly are included in biological survey protocols for fish and in forest health surveys. They also are included as endpoint responses in some chronic tests of fish and birds.

A.1.3. C-GEAE #3. Survival, Fecundity and Growth of Organisms

As discussed in Section A.1, EPA's ecological assessments have considered effects on survival, fecundity and growth in a variety of taxa. Although actions based on survival may be the most common, EPA also has made regulatory decisions based on effects on fecundity and growth of organisms identified in ERAs. For example, the pesticide chlorfenapyr was not approved by EPA on the basis of Agency concerns about reproductive risks to birds. Additionally, federal statutes and other precedents confer special status on particular kinds of organisms: endangered and threatened species, marine mammals, bald and golden eagles, and migratory birds. The remainder of this section concentrates on the basis for the special status of these organisms within the organism-level endpoints.

Laws, Regulations and Precedents: Survival, Fecundity and Growth

Endangered and threatened species. The ESA protects threatened or endangered species from "taking." To "take" is defined as to "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" (16 U.S.C. § 1532; 50 CFR Parts 14, 17 and 23). Under the Act, the term "species" includes "any subspecies of fish or wildlife or plants and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." The ESA states that it is "to be the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species and threatened species" and that "Federal agencies shall cooperate with State and local agencies to resolve water resource issues in concert with conservation of endangered species" (16 U.S.C. § 1531).[1] Thus, the provisions of the ESA are applicable to EPA actions, and the prohibition against harming individual members of threatened or endangered species and the affirmative obligation to conserve those species would include toxic effects. Additionally, the CAA (§ 112) specifically requires EPA to prevent, taking into consideration costs and other relevant factors, adverse effects to populations of endangered species in regulating major sources of hazardous air pollutants.[3]

Like other federal agencies, EPA has published regulations and taken actions to protect endangered species. For example, EPA has consulted with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service to prevent jeopardy to endangered species, as required by the ESA, for actions such as setting water quality standards and regulating pesticides. In these consultations, the attributes of concern generally have been survival, fecundity and growth, although other attributes may be important in specific cases. The National Contingency Plan (NCP) specifies that the ESA is a federal "applicable or relevant and appropriate requirement" with which Superfund remedial actions should comply under CERCLA § 121(d)(2)(A).[15] Examples of Superfund ERAs that used endangered species as endpoints include the ASARCO Tacoma site (Chinook salmon and bull trout; see Hillman and Rochlin 2001); the Metal Bank of America site (shortnose sturgeon; see Wentsel et al. 1999); and the Montrose, Iron Mountain Mine, Fort Ord and Monterey Marine Sanctuary, Camp Pendleton-Santa Margarita River and Pearl Harbor sites (U.S. EPA 1994).

Marine mammals. The Marine Mammal Protection Act[5] protects marine mammals from "taking." To "take" is defined as to harass, hunt, capture or kill; or attempt to harass, hunt, capture or kill any marine mammal. The term "harassment" means any act of pursuit, torment or annoyance that has the potential to (1) injure a marine mammal or marine mammal stock in the wild or (2) disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding or sheltering (16 U.S.C. § 1362).

Although the Act does not specifically address toxic effects on marine mammals, the special protection afforded these species by the Act implies a particular concern for their well-being. Also, the law clearly protects properties of marine mammals at the organism level.

As with threatened and endangered species, the NCP specifies that the Marine Mammal Protection Act is a federal "applicable or relevant and appropriate requirement" with which Superfund remedial actions should comply under CERCLA (§ 121(d)(2)(A)), and it cites marine mammals as examples of specific natural resources to be protected under CERCLA (Part 101 § 16).[15]

Bald and golden eagles. Prohibited actions under the Bald and Golden Eagle Protection Act[6] include to "take, possess, sell, purchase, barter, offer to sell, purchase or barter, transport, export or import, at any time or in any manner any bald eagle commonly known as the American eagle or any golden eagle, alive or dead, or any part, nest, or egg thereof of the foregoing eagles…" (16 U.S.C. § 668). To take, as defined by regulation, includes "to pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to pursue, hunt, shoot, wound, kill, trap, capture, or collect" bald eagles or golden eagles, including any "part, nest, or egg of such bird[s]" (50 CFR § 10.12).

Deaths of bald eagles resulting from secondary poisoning was an endpoint in EPA's assessment of granular carbofuran (U.S. EPA 1991a), which led to the phaseout of most uses of this pesticide. Also, EPA's ERA for PCBs in the Hudson River included survival, growth and reproduction of piscivorous birds as an assessment endpoint, with the bald eagle selected as one of the representative species of piscivorous birds (U.S. EPA 2000).

Birds. The Migratory Bird Treaty Act[7] prohibits or regulates several activities, including pursuing, taking, hunting, capturing, killing, possessing, selling, transporting or purchasing migratory birds, including their eggs and nests (16 U.S.C. § 703). This Act, based originally on a treaty between the United States and Great Britain (including Canada), has since been extended by migratory bird conventions with Mexico, Japan and the Soviet Union. Because nearly all species of birds native to the United States are protected by the Act (U.S. Fish and Wildlife Service 2001), the endpoint may be assumed to apply to native birds in general. Although the Migratory Bird Treaty Act does not specifically address toxic effects on birds, the special protection afforded these species by the Act implies a particular concern for their well-being. Also, the law clearly protects birds at the organism level. Furthermore, by Executive Order 13186, all federal agencies are required to "support the conservation intent of the migratory birds conventions by integrating bird conservation principles, measures, and practices into agency activities and by avoiding or minimizing, to the extent practicable, adverse impacts on migratory bird resources when conducting agency actions" and to "prevent or abate the pollution or detrimental alteration of the environment for the benefit of migratory birds, as practicable."[19]

EPA policies and precedents affirm the use of survival, growth and reproduction of birds in ecological assessments. The NCP specifies that the Migratory Bird Treaty Act[7] is a federal "applicable or relevant and appropriate requirement" with which Superfund remedial actions should comply under CERCLA § 121(d)(2)(A).[15] Examples of Superfund ERAs that used birds as endpoints include the Baird and McGuire site (survival and reproduction of songbirds; see Menzie et al. 1992) and the United Heckathorn site (reproductive effects on birds; see Wentsel et al. 1999). EPA's ERA for PCBs in the Hudson River included survival, growth and reproduction of insectivorous birds, waterfowl and piscivorous birds as

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[19] Exec. Order No. 13186, 66 *Fed. Reg.* 11 (Jan. 17, 2001).

assessment endpoints (U.S. EPA 2000). EPA regulations authorize the Agency to require pesticide registrants to submit tests on avian mortality and impaired avian reproduction caused by pesticides. Results from these tests, in conjunction with other available information, are used by EPA in making pesticide registration decisions. Also, EPA's involvement in bird conservation initiatives such as Partners in Flight and the North American Bird Conservation Initiative provides further support for using birds in assessment endpoints (U.S. EPA 2012).

Practicality: Survival, Fecundity and Growth

Because nearly all standard toxicity tests determine effects on the survival, and standard chronic tests include fecundity and growth of organisms, direct toxic effects on this endpoint are predicted readily. In addition, extrapolation models are available that can estimate effects on this endpoint for particular organisms and exposure routes of concern on the basis of tests conducted on other species, life stages or exposure durations or routes.

Obtaining toxicity data for threatened and endangered species is rarely possible, but SSDs, intertaxa regressions or other interspecies extrapolation models should serve to estimate effects on these species (Posthuma et al. 2002; Suter 1998). EPA research has confirmed that endangered species are not inherently more sensitive than other species to toxic effects (Sappington et al. 2001) although from a population standpoint, they may be at greater risk because of their low abundance.

Effects on marine mammals are relatively difficult to observe in the field. Die-offs of pinnipeds and cetaceans, however, are readily observed when their conspicuous carcasses appear on beaches. The toxicology of marine mammals is poorly known, and for obvious reasons, marine mammals are not included in routine toxicity testing. Effects on all mammals are routinely estimated, however, from tests performed with rodents. Exposure of marine mammals also is poorly known, although these mammals can accumulate high levels of persistent pollutants.

Eagles are highly conspicuous, and dead or debilitated eagles are more likely to be reported by the public than are most other dead or debilitated birds. In addition, federal, state and private organizations monitor eagles at various scales. Toxic effects on eagles may be predicted from standard avian toxicity tests or, more confidently, from tests with kestrels using avian allometric models to extrapolate toxicity results to eagles.

In general, the biology of birds is well known, and well-developed methods exist for surveying bird populations and communities. Both acute and chronic test protocols for birds are available, and avian toxicity data are available for most pesticides and many other chemicals. Because birds are highly mobile, often migratory and often territorial, however, demonstrating chronic effects on these organisms in the field is usually difficult.

A.2. Population-Level Endpoints

As described in Section A.1, most environmental statutes authorizing EPA activities call for protection of a diverse array of organisms. These statutes generally can be inferred to protect population-level endpoints in addition to organism-level endpoints. EPA's principles for ERA at Superfund sites exemplify EPA's concern about population-level endpoints: "Superfund's goal is to reduce ecological risks to levels that will result in the recovery and maintenance of healthy local populations and communities of biota" (U.S. EPA 1999a).

Predicting population-level impacts generally is not as straightforward as estimating organism-level effects, and as a result, explicit estimates of population effects are less common in EPA ecological assessments. Adverse effects on organisms often are inferred to indicate risk to populations and thus a cause for concern under certain EPA programs such as Superfund. Similar inferences are made for chemical reviews under TSCA.[17] In examining environmental effects of concern under TSCA, an EPA position paper reviewed several statutes spanning the period 1785 to 1978 to determine society's environmental values (U.S. EPA 1983). EPA concluded that such laws were passed to prevent any reduction, degradation or loss in the quality, quantity or utility of a resource that is valued by the public. It also concluded that chemicals could adversely affect these resources by causing an undesirable change in the population structure of a species by affecting rates of mortality, reproduction or growth and development. Thus, organism-level attributes such as mortality can be inferred to affect population-level attributes valued by society. Less commonly, EPA prepares quantitative estimates of population effects based on organism-level effects or other information.

Population-level endpoints have been assessed at EPA for commercially or recreationally valuable species such as fish, birds and shellfish.

A.2.1. C-GEAE #4. Extirpation of an Assessment Population

Extirpation can be viewed as an extreme case of a change in abundance or production of an assessment population, and thus its selection is supported by the factors cited in Section A.2.2 Additionally, extirpation of an assessment population may have qualitatively more significant impacts on ecological function and environmental values than just reduction in the size of the assessment population, as reflected in an alternative term for this population attribute: functional extinction.

Laws, Regulations and Precedents: Extirpation

Several EPA precedents exist for assessing population extirpation. For example, EPA examined the likelihood of extirpation of fish populations in northeastern lakes under the acid deposition program and vetoed a permit for a dam and reservoir project under Section 404 of the CWA,[8] in part on the basis of the projected extirpation of populations of birds of special interest (U.S. EPA 1994). A benchmark value for conductivity of fresh water is based on the protection of 95 percent of invertebrate genera from extirpation (U.S. EPA 2011). Absence of a species normally occurring in the habitat has been used as evidence of ecological risk at Superfund sites. Where designated aquatic life uses have been specified in state water quality standards, extirpation of a naturally occurring species may be considered as evidence that the water body is not attaining its designated uses.

Practicality: Extirpation

Field observations to determine whether a species is present usually are not difficult to conduct; ease of observation depends on the species, however, and care must be taken in interpreting results. Failure to observe a species expected to occur in low numbers even in the absence of stressors that is subject to substantial natural fluctuations in abundance or that is inconspicuous may not be indicative of extirpation. Demonstrating extirpation at a site also requires evidence that the species was formerly present.

In some cases, risk of extirpation can be inferred from toxicity data. Very high exposure in the field compared to exposures where toxic effects have been observed in laboratory tests suggests a high likelihood of extirpation, and conversely, very low exposure implies that extirpation is unlikely. Population modeling such as population viability analysis or ecosystem modeling may be required to estimate the likelihood of extirpation in cases in which exposure is lethal to only some individuals, effects on reproduction are expected but limited or effects are indirect. Population modeling typically requires species-specific data on parameters that are not routinely available in ERA, such as age-specific reproduction rates. Population models are available and well developed, however, and these models have been used to predict extirpation, particularly of fisheries (Barnthouse 2007; Pastorok et al. 2002). More information relevant to population models is presented in Section A.2.2.

A.2.2. C-GEAE #5. Abundance of an Assessment Population

Laws, Regulations and Precedents: Abundance

Abundance is the most common population-level endpoint considered by EPA. On occasion, EPA evaluated population models to explore effects on abundance by chemicals regulated under TSCA.[17] For example, EPA explored the risks of chloroparaffins to a rainbow trout population using a projection matrix model (U.S. EPA 1993a). Maintenance of populations of piscivorous birds and mammals was the ecological assessment endpoint for the Mercury Report to Congress (U.S. EPA 1997a).

Additionally, more than 25 estuaries have been selected as national estuaries by EPA, as authorized by the CWA.[8] Restoring or protecting populations and production of fish and shellfish for commercial and recreational use typically is among the goals of individual national estuary programs. Similarly, a goal of the Chesapeake Bay Program, a partnership among EPA and the states adjoining the Bay, is restoring, protecting, and enhancing fish and shellfish, using measures that include populations of oysters and priority migratory fish species such as striped bass.

Practicality: Abundance

Changes in population abundance may be predicted using conventional toxicity data with statistical extrapolation models and population models (Pastorok et al. 2002; Suter 2007). This approach can produce reasonable results and has been validated in controlled conditions. For example, Kuhn et al. (2001) compared a mysid shrimp population prediction from a stage-based projection matrix model with a 55-day laboratory population study involving shrimp exposed to *p*-nonylphenol. The population model projected, within a few micrograms per liter, the concentration at which population-level effects would begin to occur (i.e., 16 μg/L projected from the model vs. 19 μg/L measured from the assay). Although such projection matrix models are practical, they require more effort than normally is applied to routine ERAs.

Population abundance also may be estimated using individual-based population models or, as discussed in Section A.3, ecosystem models. Measurement of population abundance in the field may be easy (e.g., for flowering plants) or difficult (e.g., for pelagic cetaceans). Even when measurement is easy, however, distinguishing changes in abundance may be quite difficult because of temporal variance, and distinguishing differences from reference populations may be difficult because of differences in habitat quality as well as stochastic variance. The literature in ecology concerning the measurement and monitoring of various plant and animal populations is voluminous.

A.2.3. C-GEAE #6. Production of an Assessment Population

Laws, Regulations and Precedents: Production

Much of the support for C-GEAE #5, abundance of an assessment population, also applies to this endpoint. For example, the CWA sets an interim goal of "protection and propagation of fish, shellfish, and wildlife,"[8] wherever attainable which implies both abundance and production. Accordingly, efforts under the National Estuary and Chesapeake Bay programs to protect resource species involve both abundance and production. In addition, numerous federal laws and treaties have the purpose of maintaining or increasing the production of game birds and mammals, commercial fish, and timber species. Examples include the Migratory Bird Hunting and Conservation Stamp Act,[20] Wildlife Restoration Act,[21] Sport Fish Restoration Act,[22] Convention on Great Lakes Fisheries,[23] and Fish and Wildlife Act.[24] Relevant provisions include requirements to "develop measures for maximum sustainable production of fish" (Migratory Bird Hunting and Conservation Stamp Act) and "make possible the maximum sustained productivity of Great Lakes fisheries" (Convention on Great Lakes Fisheries).

Prevention of adverse effects to welfare—including but not limited to effects on soils, water, crops, vegetation, animals and wildlife—is mandated under Section 108 (§ 109) of the CAA (National Ambient Air Quality Standards).[3] EPA has included population production, among other endpoints, as an indicator of welfare. For example, EPA revised the secondary ozone standard to provide increased protection against ozone-induced effects on vegetation, such as agricultural crop loss and damage to forests (U.S. EPA 1997c). Also, EPA regulations authorize the Agency to require pesticide registrants to submit tests of pesticide effects on plant mortality and growth inhibition. Results from these tests, in conjunction with other available information, are used by EPA in making pesticide registration decisions. Changes in production of specific legume species were endpoints in a TSCA assessment of the release of recombinant rhizobia (McClung and Sayre 1994; Orr et al. 1999).

Practicality: Production

Plant production is relatively easily and commonly measured in the field. Production of animals is more difficult to measure in the field, but well-developed techniques exist and are commonly employed for fisheries, game species and pest insects. Toxic effects on production may be estimated from chronic tests that include survival, fecundity and growth. The combined effects on population production of these organismal responses may be estimated using population or ecosystem models.

A.3. Community- and Ecosystem-Level Endpoints

Abundant statutory and regulatory support exists for environmental protection at levels above the organism and population levels. This support stems from the recognition that maintaining particular organisms of concern involves preserving their surrounding environment and from appreciation for the ecosystem as a whole (see example in Text Box A.2). In the case of direct assessment of community-level endpoints, taxa richness (C-GEAE #7) and abundance (C-GEAE #8) are the two attributes addressed most commonly. Production of plant communities (C-GEAE #9), as with production of plant populations (C-GEAE #6), also has been considered by EPA in some cases.

Text Box A.2. Support of Community/Ecosystem-Level Endpoints: The Superfund Program

EPA's principles for ERA at Superfund sites state, "Superfund's goal is to reduce ecological risks to levels that will result in the recovery and maintenance of healthy local populations and communities of biota." Community effects either can be measured directly (e.g., as in benthic species diversity) or estimated indirectly (e.g., from toxicity tests on individual species) (U.S. EPA 1999a).

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[20] Migratory Bird Hunting and Conservation Stamp Act of 1934, 16 U.S.C. § 718–718j (1934).

[21] Pittman–Robertson Federal Aid in Wildlife Restoration Act of 1937, 16 U.S.C. § 669–669i.

[22] Federal Aid in Sport Fish Restoration Act of 1950, 16 U.S.C. § 777–777k.

[23] Convention on Great Lakes Fisheries of 1954, 6 U.S.T. 2836.

[24] Fish and Wildlife Act of 1956, 16 U.S.C. § 742a–742j.

Perhaps the simplest and most widely used ecosystem-level endpoint is the area (extent) of an ecosystem (C-GEAE #10). Physical structure (C-GEAE #12) also is commonly used as an endpoint in assessing aquatic ecosystems. Precedent at EPA is limited for using attributes based on ecosystem function (e.g., primary production, energy flow, total biomass, nutrient cycling) except in the case of wetland ecosystems (C-GEAE #11). Such endpoints may have limited use to date because they are somewhat abstract and not linked as directly to management goals as other endpoints. Several such endpoints are listed in Table 5-1 as potential GEAEs for future EPA consideration.

Further details about the support for community- and ecosystem-level endpoints are presented in this section in two ways. First, support spanning multiple attributes of community-/ecosystem-level C-GEAEs is described for four general categories of ecosystems for which significant precedent exists: aquatic ecosystems, wetlands, coral reefs and endangered/rare ecosystem types. Next, supporting information is presented for each of the six community/ecosystem-level C-GEAEs.

Aquatic Ecosystems

To date, the most common application of community- and assemblage-level endpoints at EPA has been to aquatic communities, particularly fish and macroinvertebrates. Section 101(a)(2) of the CWA calls for an interim goal of water quality that provides for the protection and propagation of fish, shellfish and wildlife.[8] Section 304(a) of the Water Quality Act of 1987 directs EPA to develop and publish water quality criteria and information on methods—including biological monitoring and assessment methods—that assess the effects of pollutants on the aquatic community. Aquatic community components and attributes addressed include "biological community diversity" and "productivity."[25] Taxa richness (C-GEAE #7) and abundance (C-GEAE #8) of species or trophic groups of fish and macroinvertebrate communities are used in the biocriteria of many states and in Agency guidance (U.S. EPA 1996; U.S. EPA 1999d; Yoder and Rankin 1995).

Potential community-level impacts also have been inferred and considered a basis of concern by EPA programs, based on organism-level responses. The U.S. Ambient Water Quality Criteria for Protection of Aquatic Life are based on SSDs, with the criteria set at the fifth centile (U.S. EPA 1985a); thus, they can be interpreted as protecting at least 95 percent of the species in a community. The assessment community also is commonly used in EPA programs under TSCA.[17] The Quotient Method typically is applied to the most sensitive organismal response, as well as uncertainty factors, to infer effects on a community. Organisms are chosen to represent a variety of taxonomic groups.

Ecosystem models are particularly useful for assessing secondary (indirect) effects of toxicants on community properties (Bartell et al. 1992; Pastorok et al. 2002). Models have been used to explore community-level effects, as in the case of evaluating the primary and secondary effects of chloroparaffins on top predator fish (Bartell 1990; U.S. EPA 1993a). Although examples of application of ecosystem models to the regulation of chemicals are relatively few, generic models such as AQUATOX can serve to illustrate how direct and indirect effects propagate through ecosystems (U.S. EPA 2013a).

Wetlands

The CWA forms the primary statutory basis for protection of wetlands and, thereby, the area (C-GEAE #10) and function (C-GEAE #11) of wetland communities/ecosystems. In meeting the CWA's objective of restoring and maintaining the integrity of the nation's waters under Section 404 of the Act, wetlands are considered waters of the United States and are protected from discharge of dredged and fill

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[25] Water Quality Act of 1965, Pub. L. No. 89-234, 79 Stat. 903 (1965).

material through a permit program jointly administered by the U.S. Army Corps of Engineers (USACE) and EPA. Wetlands are defined for regulatory purposes as areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support—and that under normal circumstances do support—a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas (33 CFR § 328.3(b)). The CWA provides authority for the USACE to require permit applications to avoid and minimize wetland impacts and requires EPA to develop, in coordination with the USACE, the criteria used for Section 404 permit decisions. When damages to wetlands are unavoidable, the USACE can require permittees to provide compensatory mitigation.[8]

Additionally, Executive Order 11990, *Protection of Wetlands*, states that "[e]ach agency shall provide leadership and shall take action to prevent the destruction, loss or degradation of wetlands and to preserve and enhance natural and beneficial values of wetlands in carrying out the agency's responsibilities" (Carter 1977). As an extension of this order, President George H. W. Bush in 1989 and succeeding presidents have adopted a national policy of no net loss of wetlands in recognition of the significance of wetland areas and their ecological functions. The Coastal Zone Management Act also calls for the protection of coastal wetlands.[10]

EPA has prepared various regulations and guidance documents supporting the wetland protection goals of the CWA[8] and Executive Order 11990 (Carter 1977). For example, the *Guidelines for Specification of Disposal Sites for Dredged or Fill Material* recommends consideration of potential impacts on special aquatic sites, including wetlands, referencing changes that lead to a loss of wetland status because of permanent flooding or conversion to dry land, as well as loss of functions of water purification, water storage and provision of wetland habitat (40 CFR Part 230, Subpart E).

The large number of Superfund sites located in or adjacent to wetlands has led EPA to address the impact of contamination from these sites on the extent and ecological functions of wetlands. OSWER highlights the importance of wetland protection in the directive *Policy on Floodplain and Wetland Assessment for CERCLA Action* (U.S. EPA 1985b). Under this policy, Superfund action should meet the substantive requirements of Executive Order 11990, as well as those of the *Floodplain Management* Executive Order.[26] Section 404 of the CWA also is considered a federal "applicable or relevant and appropriate requirement" with which Superfund remedial actions should comply under CERCLA Section 121(d)(2)(A).[12] Other Superfund policies that involve consideration or protection of wetlands include the Hazard Ranking System (U.S. EPA 1990; U.S. EPA 1992a), the Superfund removal process guidance (U.S. EPA 1992b), a memorandum of agreement between EPA and the U.S. Department of the Army (Page and Wilcher 1990) and the OSWER directive *Controlling the Impacts of Remediation Activities in or Around Wetlands* (U.S. EPA 1993b).

EPA's *Procedures for Implementing the Requirements of the Council on Environmental Quality on the National Environmental Policy Act* singles out wetlands by stating that "if the proposed action may have significant adverse effects on wetlands," an environmental impact statement is required (40 CFR § 6.108). EPA's *Requirements for Diagnostic-Feasibility Studies and Environmental Evaluations* requires that state and local project proposals demonstrate compliance with Executive Order 11990 (40 CFR Part 35, Subpart H, Appendix A).

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[26] Exec. Order No. 11988, 42 *Fed. Reg.* 26951 (May 25, 1977).

Coral Reefs

At present, coral reefs have not attained the same legal and regulatory stature under EPA programs as have wetlands, perhaps in part because few EPA actions involve coral reefs. Support for their protection, however, has been increasing in recent years. Taxa richness (C-GEAE #7) and area (C-GEAE #10) are the attributes of coral reef communities/ecosystems most commonly targeted for assessment and protection. Executive Order 13089 established special protection for coral reefs (Clinton 1998). In particular, "All Federal agencies…shall…utilize their programs and authorities to protect and enhance the conditions of such ecosystems." This Executive Order names the EPA Administrator as a member of the Coral Reef Task Force, which is responsible for implementing the Order. An EPA memorandum to the field specifically applies the order to EPA's responsibilities under Section 404 of the CWA, Sections 102 and 103 of the Marine Protection and Sanctuaries Act and Section 307 of the Coastal Zone Management Act (Fox and Westphal 1999). The Order also is considered a federal "applicable or relevant and appropriate requirement" with which Superfund remedial actions should comply under CERCLA Section 121(d)(2)(A).[12]

EPA's *Guidelines for Specification of Disposal Sites for Dredged or Fill Material* recommends consideration of potential impacts on special aquatic sites, including coral reefs. The guidelines refer to loss of productive colonies and subsequent loss of coral-dependent species (40 CFR Part 230, Subpart E).

Diversity is the only ecological attribute defined as a value of coral reefs in the *National Action Plan to Conserve Coral Reefs* (USCRTF 2000). A practical operational definition of that attribute is taxa richness. This document also mentions "shoreline protection, areas of natural beauty, recreation and tourism, and sources of food, pharmaceuticals, jobs, and revenues" as services of coral reefs. These services have not been used as assessment endpoints by EPA, but they could be protected by preserving the area and taxa richness of coral reefs.

The Convention on International Trade in Endangered Species (CITES), to which the United States is a party, restricts international trade in corals and other reef organisms.[13] All coral reefs in Florida are protected by either the federal or state government. Other specifically protected reef communities are found in Puerto Rico, Hawaii, the U.S. Virgin Islands, Guam, the Northern Marianas and American Samoa.

Endangered or Rare Ecosystems Types

Support for the protection of endangered and rare ecosystems, particularly in the case of terrestrial ecosystems, is less extensive and more indirect than it is for the classes of communities/ecosystems described above, but it can be identified in a variety of programs. Area (C-GEAE #10) is the primary attribute assessed for these ecosystems. Additionally, inherent in the definition of the area of endangered and rare ecosystems may be attributes such as taxa richness (C-GEAE #7) and abundance (C-GEAE #8). Consequently, the loss of these attributes could constitute loss of area of the ecosystem type as it is converted to a different ecosystem type.

Several lines of support for protecting endangered and rare ecosystems are apparent in Superfund programs. The NCP[15] specifies that, "evaluations shall be performed to assess threats to the environment, *especially sensitive habitats*" [emphasis added] (U.S. EPA 1989). The Hazard Ranking System for Superfund (U.S. EPA 1990) gives as an example of sensitive environments "particular areas, relatively small in size, important to maintenance of unique biotic communities." The Superfund removal process guidance (U.S. EPA 1992b) recommends that the On-Scene Coordinator undertake special considerations for actions that include sensitive ecosystems, which may be interpreted as calling for protection of endangered or rare ecosystem types.

Other EPA programs also consider endangered ecosystems. For example, the protocol for a screening-level ERA for hazardous waste combustion facilities calls for special consideration of areas having unique or rare ecological receptors and natural resources (U.S. EPA 1999e). EPA Regions 4, 5 and 6, as well as the Great Lakes Program Office, are developing approaches for identifying high-quality areas (critical ecosystems) for enhanced environmental protection and restoration. EPA Region 4 has been involved in the development of the Southeastern Ecological Framework as a decision support tool useful in integrating program resources for protecting and sustaining ecological processes.

EPA Region 5 also is developing an approach for prioritizing and targeting high-quality areas in the Midwest (Mysz et al. 2000). Two of the criteria for identifying these areas, also called "critical ecosystems," are (1) the presence of an indigenous ecosystem and biological community types (used as an indicator of relative ecological diversity); and (2) the numbers and rarity of native species and natural features (used as indicators of surviving relict native ecosystems).

In addition, EPA's Great Lakes Program, in collaboration with Environment Canada, has developed Biodiversity Investment Areas as natural areas along the Great Lakes shoreline, the high ecological values of which warrant exceptional attention to protect them from degradation. EPA Region 6 is using a GIS screening tool to assist in prioritizing ecological areas of concern for programs such as NEPA (Osowski et al. 2001).

In carrying out its responsibilities for reviewing environmental impact statements under NEPA, EPA has developed guidance that calls for special attention to human activities in imperiled ecosystems and identifies mitigation measures to reduce adverse impacts (U.S. EPA 1993c). Approximately a dozen "principal habitats of concern" were identified within each of six major U.S. habitat types. Ecological concerns raised by EPA to other federal agencies during review of NEPA documents have included impacts to endangered or rare ecosystems (U.S. EPA 1994).

A.3.1. C-GEAE #7. Taxa Richness of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Taxa Richness

As described in Section A.3, the most extensive support for use of this endpoint at EPA comes from measures to assess and protect the taxa richness of aquatic communities as part of water quality protection programs under the CWA.[8] Use of taxa richness as an attribute can be inferred by programs under TSCA[17] and other statutes to assess risks to a range of species across an aquatic community. Aquatic community composition is presented as an example of an assessment endpoint in Superfund ERA guidance (U.S. EPA 1997b), and community diversity or species richness is a generic endpoint for ERAs of hazardous waste combustors (U.S. EPA 1999e). Support for taxa richness of coral reef communities/ecosystems also is described in Section A.3.

EPA regional offices have considered the effects of federal projects on species diversity in decisions under NEPA, such as in an assessment of the impacts of the loss of bottomland hardwood forest on species composition of the wildlife community resulting from levee construction (U.S. EPA 1994).

Practicality: Taxa Richness

Species or taxa richness is the simplest, least controversial and most easily interpreted expression of community diversity. Changes in taxa richness are observed readily in standard biological surveys. If significant toxic effects are assumed likely to result in local extirpation of a species, changes in taxa richness may be predicted using SSDs or regression models that relate all of the species of a community or assemblage to a test species. If indirect effects are expected to result in the loss of species, ecosystem models may be used to predict species losses.

In the case of coral reefs, the taxa richness of corals is relatively easy to determine. The taxa richness of some other assemblages (e.g., fishes, sessile non-coral invertebrates) also is practical to determine. Methods for assessing the condition of coral reefs are discussed in Jameson et al. (1998). Prediction of the effects of pollutants on coral reefs is difficult because of the paucity of toxicological information for corals.

A.3.2. C-GEAE #8. Abundance of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Abundance

This endpoint shares with C-GEAE #7 the support described in Section A.3 for aquatic communities. Abundance of fish and macroinvertebrate taxa and trophic groups in sampled communities is used in the water quality biocriteria of many states and in Agency guidance. Community abundance can be inferred to be an element of ambient water quality standards and of chemical evaluations under TSCA.[17] Aquatic community composition, including a metric describing abundance, is presented as an example of an assessment endpoint in Superfund ERA guidance (U.S. EPA 1997b).

Practicality: Abundance

Abundance of communities or assemblages—as a whole or by species, taxon or trophic group—is available from most routine biological surveys. Although one can readily infer from standard toxicity tests that some changes in abundance are likely to occur, they are difficult to predict quantitatively. As discussed in Section A.3, community properties may be estimated from standard toxicity test data using ecosystem models.

A.3.3. C-GEAE #9. Production of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Production

This endpoint shares a basis in laws, regulations and precedents with C-GEAE #6, production of plant populations, through CAA, FIFRA and TSCA programs.[3,14,17] For example, the secondary ambient air quality standard established by EPA to protect public welfare for ground-level ozone (U.S. EPA 1997c) cites growth and yield reductions in tree seedlings and mature trees and impacts on forest stands and community structure resulting from these reductions.

Superfund directives and guidance identify plant production, such as productivity of wetland vegetation, as a candidate assessment endpoint (Environmental Response Team 1994a; Environmental Response Team 1994b; Environmental Response Team 1994c; Environmental Response Team 1994d). Community productivity, and in particular herbaceous plant productivity, is a generic endpoint for ERAs of hazardous waste combustors (U.S. EPA 1999e). EPA actions to control acid rain and its precursors have been based on concerns about the damage to high-elevation forests, among other effects, attributed to acid rain.

As stated in Section A.3, the CWA (§ 101(a)(2)) calls for an interim goal of water quality that provides for the protection and propagation of fish, shellfish and wildlife. Section 304(a) of the Act also lists effects of pollutants on plant life and on rates of eutrophication (i.e., excessive plant production resulting from nutrient pollution) as factors to consider in establishing pollutant limits.[8] Eutrophication has been the basis for many federal and state regulatory actions, as well as voluntary control programs, including the establishment of total maximum daily loads (TMDLs) for nutrients (U.S. EPA 1999b), controls on nutrient discharges from sources such as publicly owned treatment works and confined animal feeding operations and restrictions on phosphorus in detergents.

Practicality: Production

Eutrophication has long been a major concern of environmental managers, particularly with respect to sewage outfalls; the models for predicting effects of nutrient additions, therefore, are relatively well developed. Similarly, studies of fertilizer addition to crops, pastures and commercial forests are numerous and provide a good basis for predicting the effects of terrestrial nutrient additions on plant production. In addition, methods for measuring plant production are well developed for both terrestrial and aquatic communities. Protocols for testing toxic effects on terrestrial and aquatic plants focus on various measures of production. Toxicity data are less abundant for plants, however, than for animals.

A.3.4. C-GEAE #10. Area of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Area

The most extensive support for use of community/ecosystem area as a C-GEAE at EPA involves protection of wetlands. As discussed in Section A.3, the CWA affords special protection to wetlands, and several EPA programs reflect this emphasis.[8] Within the Superfund Program, for example, unavoidable impacts on onsite and adjacent wetland resources from current or potential exposure to hazardous substances and from implementation of select response actions are addressed in the Record of Decision for that site. Records of Decision for the New London Submarine Base in New London, Connecticut (U.S. EPA 1998c); Loring Air Force Base in Limestone, Maine (U.S. EPA 1997e); and Pease Air Force Base in Portsmouth/Newington, New Hampshire (U.S. EPA 1997f) include remedies involving compensatory wetland mitigation. Mitigation actions are tracked by long-term monitoring plans, and restoration efforts are monitored over a specified period to ensure success.

Efforts to assess and control risks to coral reefs—and to rare/endangered ecosystems generally—also serve as precedents for the use of area as a GEAE (see Section A.3). These programs, however, currently are not as extensive at EPA as are those for wetlands.

Practicality: Area

Wetlands are classified and mapped by the National Wetlands Inventory of the U.S. Fish and Wildlife Service, but determination of wetland boundaries at a given site may be difficult, particularly in areas of low topographic relief. The 1987 *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) is the current federal delineation manual used in the CWA Section 404 regulatory program for the identification and delineation of wetlands. Most effects on wetland area are readily predicted or observed because they occur as a result of processes such as dredging, filling, draining or inundation.

Coral reef area is relatively easily determined. Methods for assessing the condition of coral reefs are discussed in Jameson et al. (1998). As stated for taxa richness (see C-GEAE #7), predicting the effects of pollutants on coral reefs is difficult because of the paucity of toxicological information for corals.

An endangered or rare ecosystem type might be diminished by physical destruction, which is readily observed and quantified, or by physical conversion to another type of ecosystem (e.g., because of selective logging or grazing), which also can be readily observed and quantified if the type is defined clearly. The prediction of loss of an ecosystem type because of extirpation of many or most of the constituent organisms (e.g., as a result of an herbicide application or oil spill) is practical because it would involve severe toxicity. Loss of a type because of more subtle effects, such as changes in species composition due to differential susceptibility, to a stressor could be difficult to predict. Information useful in identifying rare and endangered ecosystem types is available from NatureServe (http://www.natureserve.org). NatureServe maintains databases on all known ecological communities in the United States, ranked from critically imperiled to secure. According to NatureServe, the completeness of inventory and classification work varies widely among states, provinces and regions.

A.3.5. C-GEAE #11. Function of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Function

Although the importance of ecosystem function is widely recognized, precedent for its use as an independent endpoint at EPA is limited except in the case of wetlands. Protection of functional attributes of wetlands is specifically targeted, for example, in EPA's *Guidelines for Specification of Disposal Sites for Dredged and Fill Material* (40 CFR Part 230), implementing Section 404(b)(1) of the CWA.[8] Commonly recognized functions of wetlands include storage and filtration of water and maintenance of habitat for fish and wildlife.

Practicality: Function

Losses of wetland functions can be inferred from loss of wetland area (see C-GEAE #10, Section A.3.4), but they are less readily observed or predicted if not accompanied by the loss of wetland area. The hydrogeomorphic method (Brinson 1993) is one approach for assessing wetland function. In support of the CWA Section 404 regulatory program, EPA, the USACE and other federal agencies have agreed to formally adopt this method to improve the assessment of wetland function.[27] Toxic effects on wetland functions or on the type of wetland community are difficult to predict.

A.3.6. C-GEAE #12. Physical Structure of Assessment Communities, Assemblages and Ecosystems

Laws, Regulations and Precedents: Physical Structure

Policy support for the physical structure of ecosystems as a C-GEAE stems from the CWA's goals of protecting aquatic ecosystems. The CWA (§ 101(a)) states that "[t]he objective of this Act is to restore and maintain the chemical, *physical*, and biological integrity of the Nation's waters" [emphasis added].[8] The importance of physical structure is reflected by EPA regulations implementing the CWA that note the following conditions of a water body that may preclude attainment of desired beneficial uses (40 CFR § 131.10(g)): "natural, ephemeral, intermittent or low flow conditions of water levels"; "dams, diversions or other types of hydrologic modifications"; and "physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality."

The *Protocol for Developing Sediment TMDLs* (U.S. EPA 1999c) lists channel modification, pool filling, filling of substrate with fine sediments and other effects on physical structure as sediment issues that can result in loss of designated uses. These changes in stream ecosystems are themselves changes in the ecosystem attributes that result in lost recreational/aesthetic or other uses, not simply stressors that affect biological endpoints.

Physical structure has been a factor in setting the designated use of streams in state water quality standards. For example, in Ohio, a designated use of Modified Warmwater Habitat applies to streams with extensive and irretrievable physical habitat modifications.

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[27] *The National Action Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions*, 62 *Fed. Reg.* 33607 (June 20, 1997).

Practicality: Physical Structure

Physical characteristics often are readily observed or measured at sites being assessed and usually are recorded in biological surveys. Protocols exist for measuring many aquatic habitat attributes (see, for example, U.S. EPA 1999d). In addition, most of the actions that modify the physical structure of water bodies (e.g., channelization, dam construction and operation, water withdrawals, culvert installation) have obvious effects on structure that are readily predicted. Other effects, such as changes in hydrology resulting from changes in land use, are more difficult—but still possible—to model.

A.4. Officially Designated Endpoints

The C-GEAEs in this section do not fall neatly into the organism/population/community/ecosystem hierarchy used to organize the other C-GEAEs, but they are important to EPA nonetheless. Habitat for endangered species (C-GEAEs #13 and #14) is highlighted because of the specific protections it receives under the ESA.[1] Habitat has not been chosen as a C-GEAE for other categories of organisms because it is the organisms that are valued directly, whereas by definition, habitat is that which supports organisms and thus is valued indirectly. Of note is that habitat here is distinguished from communities and ecosystems, which may be valued inherently, as discussed in Section A.3. Ecological properties of special places (C-GEAE #15) can encompass attributes from all levels of biological organization. Special places are identified because of the legal and other support for their protection or because of their ecological importance.

A.4.1. C-GEAEs #13 and #14. Area and Quality of Habitat for Threatened or Endangered Species

Laws, Regulations and Precedents: Area and Quality of Critical Habitat

The obligation to protect endangered and threatened species under the ESA includes protection of the critical habitats on which they depend.[1] Thus, the legal and regulatory basis for protecting endangered species described under C-GEAE #3 generally also applies to this endpoint. For example, the Superfund NCP specifies that "evaluations shall be performed to assess threats to the environment, especially sensitive habitats and *critical habitats of species protected under the Endangered Species Act*" [emphasis added].[15] EPA's *Requirements for Diagnostic-Feasibility Studies and Environmental Evaluations* requires that state and local project proposals determine whether significant adverse effects on critical habitat of endangered species would occur (40 CFR Part 35, Subpart H, Appendix A).

Practicality: Area and Quality of Critical Habitat

Designated critical habitat is readily identified, and determining whether it will be destroyed (reduced area) or adversely modified (reduced quality) should be practical. Although critical habitat has not been officially designated for many endangered or threatened species, federal documents such as listing decisions and recovery plans typically discuss the distribution and ecological requirements of listed species. If species or taxa that are components of critical habitat are identified, toxic effects can be predicted and the response to pollutants evaluated.

A.4.2. C-GEAE #15. Ecological Properties of Special Places

Laws, Regulations and Precedents: Special Places

The legislative acts establishing national parks and monuments, wildlife refuges, wilderness areas, wild and scenic rivers, recreation areas, marine sanctuaries, and other special places establish their status and indicate the properties for which the protected status was provided. Several statutes either give EPA a role in designating special places or direct EPA to consider environmental impacts to such places in administering Agency programs. The CWA directs EPA to administer the National Estuary Program and allows states to designate water bodies as Outstanding National Resource Waters, which then receive increased protection through water quality standards.[8]

The CAA also contains several provisions for special places. Section 160 of the CAA establishes that a purpose of the Act is "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value." Section 162 designates national and international parks, wilderness areas, and memorial parks of a certain size as "Class I" areas that merit the highest level of protection from air pollution.[3] Other special places cited in both the CAA and the CWA include the Great Lakes, Chesapeake Bay and Lake Champlain.[3,8]

In EPA regulations and guidance, the NCP cites special places such as national marine sanctuaries and estuarine research reserves as natural resources to be protected under CERCLA.[15] Superfund removal process guidance (U.S. EPA 1992b) recommends that the On-Scene Coordinator undertake special considerations for actions that include wild and scenic rivers. EPA procedures for implementing NEPA require preparation of an environmental impact statement if "the proposed action may have significant adverse effects on parklands, preserves, or areas of recognized scenic, recreational, archeological, or historic value" (40 CFR § 6.108). The *Guidelines for Specification of Disposal Sites for Dredged or Fill Material* recommends consideration of potential impacts on special aquatic sites, including sanctuaries and refuges (40 CFR Part 230, Subpart E). The protocol for screening-level ERAs for hazardous waste combustion facilities calls for special consideration of areas having legislatively conferred protection (U.S. EPA 1999e).

Practicality: Special Places

Special places and their important ecological properties usually can be defined readily. Given the diverse set of ecological properties at different places, making overall statements about the practicality of this endpoint is not possible. Potentially, all of the surveying, testing and modeling methods discussed in the previous sections could be applicable.

APPENDIX B. TYPES OF VALUES ASSOCIATED WITH ASSESSMENT ENDPOINTS

The U.S. Environmental Protection Agency's (EPA's) ecological risk assessment (ERA) guidelines (U.S. EPA 1998a) define an assessment endpoint as "an explicit expression of the *environmental value* that is to be protected, operationally defined by an ecological entity and its attributes" [emphasis added]. In the context of the guidelines, an *environmental value* refers to a component of the environment (or an ecological entity) that society values, with some examples being endangered species and commercially or recreationally important species. The literature on environmental valuation covers a wide range of ecological systems and components: for example, bays (Kahn 1985), wetlands (Barbier 1993), riparian corridors (Lant and Tobin 1989), deserts (Richer 1995), recreation areas (Adamowicz et al. 1994) and wilderness or "unspoiled" natural areas (Hanink 1995; Kopp and Smith 1993; Randall and Peterson 1984). In many of these studies, ecosystems are conceptualized as having *assets* or structural components such as energy resources, minerals or timber; *services* or natural functions benefitting society (e.g., ground water recharge, flood control, the absorption or assimilation of pollutants); or other *attributes* provided by the whole ecosystem, such as biological diversity, cultural uniqueness or natural heritage (Daily et al. 1997; Westman 1977).

Table B-1 presents one way of organizing environmental values, drawing on Blomquist and Whitehead (1995), Daily (2000), Ehrlich and Ehrlich (1981), MacLean (1995), Primack (1993), and Freeman (1984; 1993). The table is not intended to represent a definitive or comprehensive list of environmental values. Rather, it is intended to illustrate the breadth of values that may be cited in support of a conventional generic ecological assessment endpoint (C-GEAE).

Table B-1. Examples of Environmental Value Categories

Value	Definition and Examples of Corresponding GEAEs
Consumptive	The value of commodities produced by the environment such as food, energy, timber, fiber, and pharmaceutical and industrial products. • Area of ecosystems: timber and fuel production by trees. • Production of an assessment population: commercially valuable fisheries. • Extirpation of an assessment population: commercially valuable furbearers.
Informational	The value of natural structures, chemicals or processes as models for anthropogenic structures, chemicals or processes (e.g., pharmaceuticals, synthetic commodities, engineering designs). Also see option value. • Extirpation of organisms: as sources of model adaptations to extreme environments. • Taxa richness of communities: highly diverse communities may be valuable sources of bioactive chemicals as models for pharmaceuticals.
Functional	The value of ecological functions benefitting public health and welfare (e.g., pollen and seed dispersal, water retention and purification, detoxification of wastes, moderation of weather extremes). In some cases, ecosystems are reestablished to make use of their functional value for remediation. • Ecosystem function: water retention and purification by wetlands. • Abundance of an assessment community: water and soil retention by forests. • Abundance of an assessment population: pollination by insects.

Table B-1. Examples of Environmental Value Categories (cont.)

Value	Definition and Examples of Corresponding GEAEs
Recreational	The value of recreational opportunities such as fishing, birding, boating and hiking. In some cases, this is a passive use of a resource, but in others (e.g., tourism) it is an economic activity. • Physical structure of an ecosystem: boating and fishing. • Survival, fecundity and growth of organisms (migratory birds): birding and hunting. • Properties of special places: camping, hiking and boating.
Educational	The value of academic and nonacademic educational opportunities, including nature and scientific study. • Properties of special places: parks and refuges for nature study and research. • Area of ecosystems: environmental education sites.
Option	The value to future generations of preserving the option of using the environment at some future time. Option value also includes human welfare gains or net benefits associated with delaying a decision when uncertainty exists about the payoffs of certain alternatives or when one of the choices involves an irreversible commitment of resources. • Area and function of ecosystems. • Properties of special places. • Abundance of assessment populations.
Existence	Value ascribed to the existence of ecological systems independent of any direct services or functions. Aesthetic, moral, cultural, religious or spiritual grounds may be cited in support of this type of nonuse value. • Area and quality of critical habitat for endangered species. • Gross anomalies and kills of organisms. • Properties of special places.

Each GEAE presented in this document relates to one or more of these environmental values. For example, an “assessment population” and its attributes may be used to represent a commercially and recreationally valuable fish or wildlife population (consumptive and recreational values). Such an assessment population also could represent a species population that is valued as a learning tool (educational value), and protected for cultural and aesthetic reasons (preservation value). Table B-1 provides further examples of how each C-GEAE may correspond with these values. The generic ecosystem services endpoints (ES-GEAEs) correspond even more directly to these values; accordingly, the values are used to organize the ES-GEAEs in Table 3-1.

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