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Ecosystem Services as Assessment Endpoints in Ecological Risk Assessment

Technical Background Paper

Risk Assessment Forum
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NOTICE

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Preface

Ecological risk assessment (ERA) evaluates the likelihood that adverse ecological effects may occur or are occurring because of exposure to one or more stressors. An early and critical step in conducting an ERA is deciding which elements of the ecological system will be selected for evaluation. This step often is challenging because of the remarkable diversity of species, ecological communities and ecological functions from which to choose and statutory ambiguity regarding what is to be protected. The purpose of this document is to build on existing U.S. Environmental Protection Agency (EPA or the Agency) guidance and experience to assist those who are involved in ERAs in carrying out this step. It establishes the technical foundation needed to support a revision of the Agency's *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment* (USEPA 2003). The revision will expand the initial list of GEAEs to include a broader range of ecosystem services and address more explicitly the linkages between the original GEAEs and ecosystem services.

This document was prepared by a Technical Panel under the auspices of EPA's Risk Assessment Forum. The Risk Assessment Forum (the Forum) was established by the Agency to promote scientific consensus on risk assessment issues and incorporate this consensus into appropriate risk assessment guidance. To accomplish this mission, the Forum assembles experts from throughout EPA in a formal process to study and report on these issues from an Agency-wide perspective. This document reflects the Forum's long-standing commitment to advancing ERA through its Ecological Oversight Committee and is intended to supplement the use of the Forum's *Guidelines for Ecological Risk Assessment* (USEPA 1998). Following the publication of the ERA guidelines, the Forum surveyed ecological risk assessors from across the Agency to prioritize and select risk assessment topics for further development. Additional guidance on assessment endpoints emerged as one of the highest priority topics, resulting in the development of the GEAEs (USEPA 2003). A subsequent EPA colloquium sponsored by the Forum to consider high priorities identified a need for additional guidance on incorporating ecosystem services in ERAs across Agency programs (USEPA 2010). As a result, the Ecological Oversight Committee appointed the Technical Panel that developed this document.

The primary goal of this background paper is to provide a technical basis for the incorporation of ecosystem services to enhance ERA at EPA, and thereby improve ecological risk management and policy decisions. This document is not a regulation, however, nor is it intended to substitute for federal regulations. It describes general concepts and principles and is not prescriptive. Risk assessors and risk managers at EPA are the primary audience; the document might also be useful to those outside the Agency.

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Acronyms and Abbreviations

a.i.	active ingredient
ANC	acid neutralizing capacity
ARAR	applicable or relevant and appropriate requirement
BERA	baseline ecological risk assessment
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CEQ	Council on Environmental Quality
COPC	contaminant of potential concern
CRLF	California Red-Legged Frog (*Rana draytonii*)
CSS	coastal sage scrub
CWA	Clean Water Act
DWH	Deepwater Horizon
EFED	Environmental Fate and Effects Division
EPA	U.S. Environmental Protection Agency
EPF	ecological production function
EPT	Ephemeroptera, Plecoptera and Trichoptera
ERA	ecological risk assessment
ESA	Endangered Species Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GEAE	generic ecological assessment endpoint
lb	pound
LOC	level of concern
MAGIC	Model of Acidification of Groundwater in Catchments
NAAQS	National Ambient Air Quality Standard
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NO_x	oxides of nitrogen
NRDA	Natural Resource Damage Assessment
OAQPS	Office of Air Quality Planning and Standards
OPA	Oil Pollution Act
OPP	Office of Pesticide Programs
PCB	polychlorinated biphenyl
REA	Risk and Exposure Assessment
RQ	risk quotient
SARA	Superfund Amendments and Reauthorization Act of 1986
SLERA	screening-level ecological risk assessment
SO_x	oxides of sulfur
TFM	3-trifluoromethyl-4-nitrophenol, known commercially as Lamprecid®
USFWS	U.S. Fish and Wildlife Service
WTP	willingness to pay

Executive Summary

The objective of this background paper is to establish the technical foundation needed to (1) enhance the societal relevance and responsiveness of ecological risk assessment (ERA) in environmental decision making by incorporating ecosystem service assessment endpoints and (2) support the revision of *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment* (USEPA 2003). This document describes the rapidly emerging concepts of ecosystem services and the rationale for their use as important considerations in environmental decisions. A recommendation for how to relate ecosystem service assessment endpoints to conventional assessment endpoints and measures of effect is made. This document expands on the conventional assessment endpoints in the GEAE by proposing example generic ecosystem service assessment endpoints for inclusion in ERA. Exploratory case studies illustrate how ecosystem service assessment endpoints add or can add value to decisions commonly made by the U.S. Environmental Protection Agency (EPA or the Agency). Finally, the document discusses next steps for incorporating ecosystem service assessment endpoints in ERAs and the research needed to enhance their value for informing environmental decisions.

ERA is a science-based process that evaluates the likelihood that adverse ecological effects may occur or are occurring because of exposure to one or more stressors. The focus of an ERA is on assessment endpoints that are explicit expressions of the environmental values to be protected (USEPA 1998). In 2003, the Agency developed a set of GEAEs that were based on environmental legislation and EPA's policies and precedents. These GEAEs were broadly described assessment endpoints applicable in a variety of environmental management contexts.

Societal values (the specific values that people hold for aspects of the environment) typically have been considered only generally when selecting conventional assessment endpoints. Awareness is growing, however, that improved environmental management can be achieved by considering more explicitly the benefits that humans receive from ecosystems. The biotic and abiotic components of a functioning ecosystem that interact to produce the outputs from which humans can derive ecological benefit are termed "ecological production functions" (EPFs). Changes in EPFs are related directly to ecological benefits, which can be expressed through economic analysis or other valuation methods. A major scientific requirement of an ecosystem service-based risk assessment is to understand EPFs and the measures of ecosystem functioning and condition that are essential for determining the production of ecosystem services. Together, this information can be used to evaluate changes in production of ecosystem services based on changes in the condition of the ecosystem as influenced by stressors and management actions.

The central role played by societal values in decision making requires that the outputs of ERA be amenable to market and nonmarket valuation so that the environmental, economic and social dimensions of ecological risk can be integrated, thereby giving risk managers a more complete, holistic accounting of the tradeoffs involved with various decision alternatives. The outputs of ecological processes can be translated directly to monetary values or expressed in nonmonetary units, such as a relative scale of benefits. Casting assessment endpoints in terms of ecosystem services not only allows for more transparency in the decision-making process, but also enables decision makers to make more fully informed, scientifically and societally defensible environmental management decisions. Some of EPA's current statutory and regulatory mandates can be interpreted to incorporate the concept of ecosystem services into the decision-making process.

The five case studies included in this document reflect a broad range of EPA decisions and illustrate how the ecosystem services concept has been or could be used to inform and communicate environmental management decisions. The case studies also serve as examples of how ecosystem service assessment endpoints can complement conventional assessment endpoints in Agency ERAs. The decisions addressed by these case studies range in scale from national to local and consider issues ranging from acidification and nutrient enrichment to invasive species, species extirpation, endangered species and remediation of hazardous waste sites. The decisions and regulatory authorities reflected include National Ambient Air Quality Standards (NAAQS) under the Clean Air Act (CAA);[1] pesticide reregistration under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA);[2] benchmarks for stream invertebrates under the Clean Water Act (CWA);[3] threatened and endangered species assessments under the Endangered Species Act (ESA);[4] and cleanup of Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[5] and Superfund Amendments and Reauthorization Act (SARA).[6]

The case study in support of potential secondary NAAQS for the oxides of nitrogen and sulfur (NO_x and SO_x) notes that language in the CAA supported selection of ecosystem service assessment endpoints in the assessment. The advantages of doing so included the ability to provide additional meaningful input for consideration of various options for the secondary standard and to facilitate clearer communication to EPA's Administrator and the public of the additional ramifications associated with those options. Several other case studies highlight the linkages that can be drawn between conventional assessment endpoints and those linked more closely to ecological benefits.

Ecosystem services are recommended as a useful concept in 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. Incorporating ecosystem services into the decision-making process will promote balanced consideration of environmental, economic and societal elements to inform sustainable decisions. Using ecosystem services as assessment endpoints provides ERA outputs that society can appreciate and readily value. Generic ecosystem service assessment endpoints can help guide ERA planning when they are considered during problem formulation by tailoring the endpoints to the specific environmental and decision contexts. In some cases, the qualitative outputs of the risk assessment can be sufficient to inform a decision. In other cases, quantitative evaluation of tradeoffs between alternative decision options is necessary. Ecosystem service assessment endpoints can complement conventional ecological assessment endpoints by clarifying to stakeholders and the public the benefits and costs a decision will have on society.

The *Millennium Ecosystem Assessment* (MEA 2005) and notable predecessor efforts (Costanza et al. 1997; Daily 1997) brought international attention to the contributions made by ecosystems to human well-being. The science underlying environmental policy based on this awareness continues to evolve rapidly. Continued research is needed to develop further the concepts, information and tools required to incorporate ecosystem service assessment endpoints in ERA routinely. In addition to research, training opportunities for ecological risk assessors and risk managers are necessary to enable them to understand better how ecosystem services can be used in the ERA and decision-making processes.

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[1] 42 U.S.C. § 7401 et seq.
[2] 7 U.S.C. § 136 et seq.
[3] 33 U.S.C. § 1251 et seq.
[4] 16 U.S.C. § 1531 et seq.
[5] 42 U.S.C. § 9601 et seq.
Pub. L. No. 99-499, 100 Stat. 1613 (October 17, 1986).

Section 1. Introduction

1.1. Purpose

The objective of this background paper is to establish the technical foundation needed to (1) enhance the societal relevance and responsiveness of ecological risk assessment (ERA) in environmental decision making by incorporating ecosystem service assessment endpoints and (2) support the revision of *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment* (USEPA 2003). The revised GEAE document will expand the initial list of GEAEs to include a more comprehensive range of ecosystem services and address more explicitly linkages between the original conventional GEAEs and ecosystem services. This paper describes the rapidly emerging concepts of ecosystem services and the rationale for their use as important considerations in environmental decisions. It suggests how ecosystem service assessment endpoints can be related to (or extrapolated from) conventional assessment endpoints and measures of effect that historically have been used by the U.S. Environmental Protection Agency (EPA or the Agency) in ERA. It also expands on the GEAE concept by proposing example generic ecosystem service assessment endpoints. Exploratory case studies serve to illustrate how ecosystem service assessment endpoints have added or can add value to decisions commonly made by the Agency. The paper recommends incorporating ecosystem service assessment endpoints into ERAs and identifies needed research to enhance their value for informing environmental decisions.

1.2. Conventional Assessment Endpoints and Measures of Effect

ERA is a science-based process for evaluating the likelihood that adverse ecological effects may occur or are occurring because of exposure to one or more stressors. The focus of ERA is on assessment endpoints (i.e., explicit expressions of the environmental values to be protected) that are defined operationally by ecological entities and their attributes (USEPA 1998). The meaning of the term "ecological entity" is intentionally broad and can include a species, a specific habitat or an ecological function. For any particular ERA, assessment endpoints are identified that are relevant to management goals and the decisions to be informed, reflect the ecology of the site and pertain to the stressors that are present or expected. Ecological relevance, susceptibility to the stressor and relevance to management goals are the key considerations when selecting assessment endpoints responsive to the needs of the decision maker (USEPA 1998). Attention to the first two of these considerations helps ensure the scientific credibility of the ERA; attention to all three enhances the significance of assessment results to decision makers and the public.

When assessment endpoints cannot be evaluated directly because of technical or other limitations, risk practitioners rely on proxies, termed measures of effect, for the assessment endpoints. The use of measures of effect in an ERA necessitates extrapolation between the responses quantified and those expected of the assessment endpoints. This extrapolation introduces additional uncertainty to assessment results (see Munns [2002] for a broad overview of extrapolation issues in risk assessment).

Selecting assessment endpoints and measures of effect responsive to the needs of decision makers and the public is a challenging endeavor, partly due to the diversity and complexity of ecological systems, components and functions. In response to a recommendation for improving ERA and ecological risk management within EPA (Suter 2000), the Agency developed a set of generic GEAEs that are described broadly (e.g., abundance of an assessment population) and can be applicable in a variety of environmental management contexts. These endpoints are based on environmental legislation and EPA's policies and precedents. Therefore, they cover EPA's range of concerns for the protection of ecological entities and functions (Suter et al. 2004; USEPA 2003).

An initial set of 15 GEAEs was developed in *Generic Ecological Assessment Endpoints (GEAEs) for Ecological Risk Assessment* (USEPA 2003) to help guide planning of the ERAs that support the array of the Agency's environmental protection decisions. GEAEs in this set were selected for their usefulness for informing EPA decisions, the practicality of their measurement and the clarity with which they can be defined. Importantly, EPA (USEPA 2003) describes relationships between the individual GEAEs and several of the environmental values that the public ascribes to ecological entities and processes. It also encourages development of additional GEAEs to enhance coverage of assessment scenarios.

1.3. Ecosystem Services

Explicit in the definition of assessment endpoint is that the entity and its attribute(s) are valued. In other words, an assessment endpoint represents a component of nature that society finds desirable and that merits consideration during the environmental decision-making process (USEPA 2003). An example of a valued component of nature might be a species that is endangered, particularly "charismatic" or commercially important. Similarly, a valued component of nature might be a unique community of species, a cherished landscape mosaic or a culturally significant landform. According to the broad definition of ecological entity that was established in the *Guidelines for Ecological Risk Assessment* (USEPA 1998), ecological functions such as nutrient retention and primary production of biomass can also be considered valued components of nature. More typical in ERAs contributing to EPA's environmental protection mission are assessment endpoints representing structural components of nature (see also Munns et al. 2009), such as the abundance of benthic infaunal invertebrates. The importance to natural systems of many endpoints considered important by ecologists, however, can be difficult to communicate to nonscientists and the lay public.

Societal values typically are considered only qualitatively when selecting assessment endpoints, such as favoring birds more than insects because of their perceived greater value to risk managers and stakeholders. In recent years, ecologists and social scientists have asserted that improved environmental management can be achieved by considering more explicitly the benefits that humans receive from ecosystems. In a broad sense, the contributions of ecological systems to the vitality of humans can be considered as ecosystem goods and services, abbreviated hereafter as "ecosystem services" (Text Box 1). Ecosystem services are the outputs of functioning ecosystems that contribute to human well-being. Generally included in this definition are the provisioning of goods (e.g., food, fiber, shelter, clean air and water) and ecological processes (e.g., regulating biological productivity, material cycling, climate). The paramount importance of ecosystem services to humans and society has been highlighted in multiple assessments (Daily 1997; Daily et al. 1997; MEA 2005; Stahl et al. 2007).

Text Box 1. Ecosystem Services

Ecosystem goods and services provide the life-sustaining benefits that people receive from nature, including clean air and water, food, a stable climate, recreation opportunities, aesthetic enjoyment and cultural connections. Ecosystem services are essential to human health and well-being, and yet their importance often is not perceived or is taken for granted as being free.

Ecosystem services arise from the structures and functions of ecosystems. For example:

- *Fertile soils* are needed to produce crops. Soil quality depends on its **structure** (determined by its mineral and organic matter content, particle size and moisture); the **functions** of the soil biota (e.g., worms, fungi, bacteria) that govern soil structure; and the availability of nutrients.
- The ability of wetlands to reduce *flooding risks* depends on their **structure** (determined by their morphology, plant communities and soils).
- Wetlands also *purify water* through a variety of physical and biological **functions.**

This paper provides technical background information to support the explicit consideration of ecosystem services in ERA. It explores how this enhancement could benefit the Agency and the broader environmental management community by providing societally relevant information to risk management decisions and a more transparent means of communicating risk. The costs and ecological benefits of protection, remediation and restoration then can be cast in terms of contributions to human well-being through quantification of ecosystem service losses or gains. An explicit focus on ecosystem service assessment endpoints in ERA is consistent with the increasing emphasis on the importance of ecosystem services in environmental management decisions (Daily et al. 1997; Dale et al. 2008; MEA 2005) and thus should increase the value of assessment results to decision making more generally. A similar recommendation was made by EPA (USEPA 2006) to develop generic endpoints that encompass key ecosystem goods and ecosystem services for routine consideration in the ecological benefits assessments that support benefit-cost analyses of environmental policy and regulation.

Section 2. Ecosystem Services as Assessment Endpoints

2.1. Concepts and Definitions

Understanding the process whereby ecosystem services can be introduced as assessment endpoints in a risk assessment is aided by understanding the basic concepts and definitions described is this section. This section concludes with a characterization of advantages of ecosystem services as assessment endpoints and a discussion of how they can be selected.

EPA (USEPA 2006) defined ecosystem services as the outputs of ecological processes that contribute to social welfare or have the potential to do so in the future. An output can include any result potentially affecting the condition of the environmental system (including humans); the term is not limited to commodities that humans might use directly. The biotic and abiotic components of a functioning ecosystem interact to produce the outputs (e.g., clean water for drinking; food for consumption; fiber for clothing, construction and ornamentation) from which humans can derive ecological benefit. Such ecological production functions (EPFs) (see Text Box 2 and Figure 1) generate the ecological outputs that form the basis of human survival and prosperity.

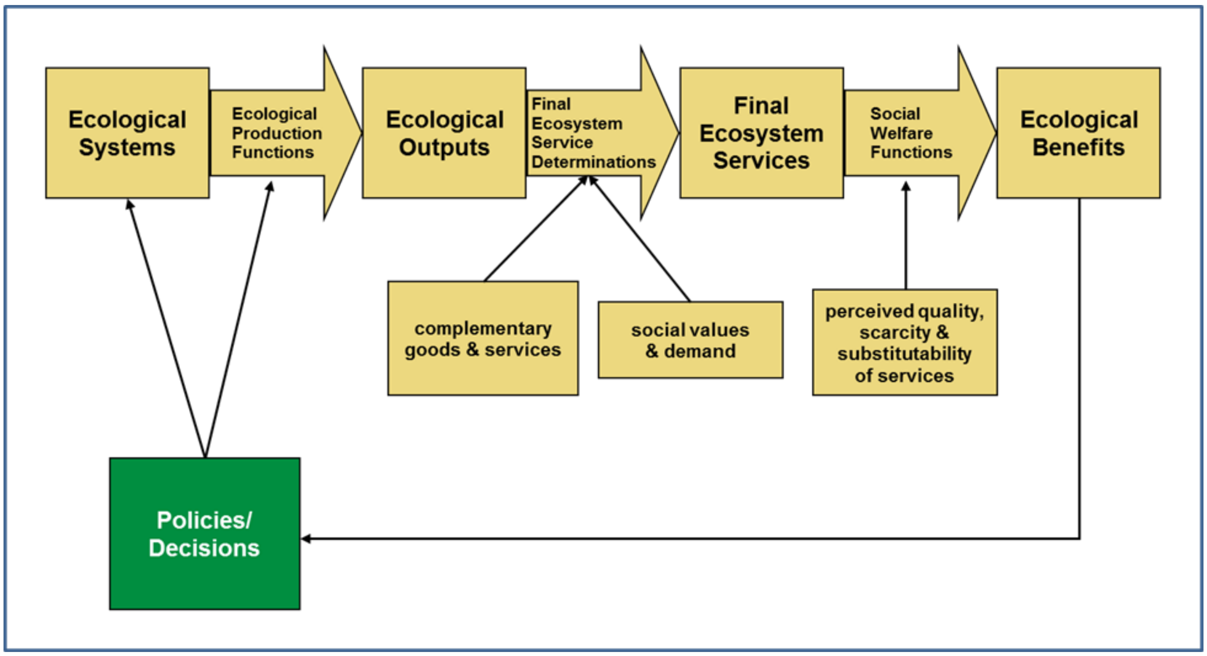
Text Box 2. Ecological Production Function

An EPF consists of the types, quantities and interactions of natural features required to generate observable and measurable ecological outputs. For example, the biophysical characteristics of a coastal wetland (e.g., flooding regimes, salinity, nutrient concentrations, plant species abundance, predator and prey abundances, climate) can influence the abundance of a population of watchable wading shorebirds (an ecological output). When combined with complementary goods and services, and when valued and demanded by humans, the outputs of EPFs are ecosystem services that benefit people.

To benefit humans and society as an ecosystem service, an ecological output must be valued and demanded by people (explicitly or otherwise). Biological production of a thriving population of trout without fishers to catch them or other recreationists to enjoy them would not benefit society directly. A demand by consumers (now or in the future) is required for that trout population to be an ecosystem service that ultimately provides ecological benefit to society. Complementary goods and services—usually built infrastructure or location characteristics—also determine whether ecological outputs are ecosystem services (Wainger et al. 2001; Munns et al. 2015). Many factors contribute to the social welfare functions that influence the ecological benefits humans receive from ecosystem services and thus enable ecological benefits to be realized (Wainger and Mazzotta 2011). They include perceived quality, scarcity and substitutability of ecosystem services. Changes in the ecological benefits that humans and society receive as the result of different policy options or risk management alternatives can inform selection among those options or alternatives (Figure 1).

Not everything that nature produces benefits humans directly or is valued by people explicitly. For example, the ecological interactions and processes that support a viable aquatic insect community that benefits a population of trout might not provide any direct ecological benefit to shoreline residents and in fact might be considered a nuisance (as is the case for mosquitoes). Further, such ecological processes might go unrecognized by many people as ultimately contributing to their well-being. Yet without those processes being part of the EPF of the thriving trout population, humans could not derive ecological benefit from recreational trout fishing opportunities. In this example, maintenance of the aquatic insect community is viewed as an intermediate ecosystem service. Intermediate ecosystem services are those functions (or components) of nature that are not directly enjoyed, consumed or used to yield human well-being but are important for the production of final ecosystem services, defined as those components of nature that are directly enjoyed, consumed or used to yield human well-being, as defined in Boyd and Banzhaf (2007) (also see Ringold et al. 2013). Although essential to providing ecosystem services and ecological benefits to humans, structural and functional properties of ecosystems (intermediate ecosystem services) are not necessarily final ecosystem services, although they can be critical parts of EPFs. Final ecosystem services, as defined here, are those that directly benefit society. A thriving trout population in a stream cannot provide recreational ecosystem services if the stream is inaccessible or closed to fishing. That final ecosystem service is not provided until it is used or otherwise enjoyed. The distinctions between intermediate and final ecosystem services sometimes might not be clear-cut. For example, people who enjoy viewing aquatic insects (e.g., dragonflies) benefit directly from a viable aquatic insect community and place a positive value on its existence; therefore, maintenance of a viable aquatic insect community could be considered a final ecosystem service to "bug watchers."

Figure 1. The potential relationships among ecological systems, ecosystem services, ecological benefits and environmental decisions



Note: In practice, policies and decisions may be influenced by changes in ecological systems or in ecosystem services without economic analyses of ecological benefits.
Source: Munns et al. (2015).

As conceptualized in Figure 1, environmental policies and decisions influence the production of ecosystem services by altering characteristics of ecological systems and the components of EPFs through processes such as the regulation of stressors and restoration of habitat. Projected changes in the ecological benefits enjoyed by society derived from the affected ecosystems can be used to inform choices among policy alternatives during the decision-making process. An understanding of the tradeoffs among benefits that result from selection of one alternative versus another can be compared to the costs to society of implementing each alternative in a formal or informal benefit-cost analysis. Because such analyses are based largely on the values of people and society, ecological risk assessment (ERAs) that provide an understanding of how different policy options might affect the delivery of ecosystem services and the ecological benefits that they provide should be more informative to decision makers than ERAs that only evaluate risks to more conventional assessment endpoints. The reason is that conventional assessment endpoints are potentially, and often, esoteric from the layperson's perspective.

Within the general construct of the risk assessment-risk management paradigm currently employed by EPA (NRC 1983), ERA focuses on ecological systems that are or can be exposed to stressors that can alter those systems. The conceptualization in Figure 1 differs in that the ecological system is viewed from a perspective of producing ecological outputs and services. By framing assessment endpoints in terms of ecosystem services, the environmental, economic and societal dimensions of ecological risk can be better integrated, thereby giving risk managers a more complete, holistic accounting of the benefits and costs of decisions. For example, consider a proposal to fill a headwater stream with mining overburden. Conventional ecological assessment endpoints might focus on macroinvertebrate or fish taxa, expressed as changes in species richness or occurrence of taxa. Although easily measured, these endpoints might not readily translate into ecological benefits. In contrast, an assessment framed around ecosystem services might consider the processes of the stream ecosystem that support not only biodiversity but also potentially water quality, water supply, recreational fishing opportunities and other ecosystem services. Whereas deriving a reliable economic[7] or societal value for biodiversity is difficult if not impossible, the values of water quality, water supply and recreational fishing can be quantified with reliable economic methods (Pittman and McCormick 2010). Thus, the use of ecosystem services within ERA can allow for a more holistic, systems approach to decision making, incorporating ecological, economic and societal elements.

The language of ecosystem services varies among users and institutions; therefore, consistency in the use of terminology is essential. The consistent use of ecosystem services terminology will help ensure commonality across broad scales of decisions (local to national) and across policy settings, while ensuring that these decisions and their impacts are clear to the public. Definitions of several commonly used terms and examples of their use are listed in Table 1 (see Munns et al. 2015).

2.2. Societal Values

Good environmental decisions are informed by the values that society places on the services provided by ecosystems. The central role played by societal values in decision making requires that the outputs of ERA be amenable to valuation so that the environmental, economic and societal dimensions of ecological risk are integrated. This provides risk managers a more complete, holistic accounting of the tradeoffs involved with various decision alternatives.

Valuation is the act or process of estimating the worth, merit or desirability of a wide variety of environmental conditions in common units that can be aggregated and compared (USEPA 2006). The values of outputs of ecological processes (e.g., food) that are sold and bought in markets can be described directly in monetary terms. Values also can be expressed in nonmonetary units, for example, on a relative scale of benefits. A common method for estimating the value of ecosystem services lacking market values is to determine how much money consumers or potential consumers are willing to pay for changes in ecological benefit or accept for foregoing changes in ecological benefit. Although less precise than market measures, indirect methods are commonly employed by economists to estimate values for nonmarket ecosystem goods and services (see Appendix A).

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[7] Economic in this context does not necessarily imply “monetary” or “monetization.” According to standard definitions (e.g., that provided by Mansfield and Yohe [2003]), economics “is concerned with the way in which resources are allocated among alternative uses to satisfy human wants.” As such, economics as a science is concerned with understanding why people make the choices that they do. These choices need not be quantified in monetary terms.

Table 1. Common terminology associated with the ecosystem services concept

Term	Definition
Benefit-cost analysis (also, cost-benefit analysis)	A formal quantitative and sometimes qualitative evaluation of the benefits to be derived from a decision or action compared to the costs incurred by implementing that decision or action. Benefits and costs may include market and nonmarket values.
Complementary goods and services	Inputs (usually built infrastructure or location characteristics) that allow an ecosystem good or service to be used by complementing the ecological condition. For example, complementary goods and services that allow a population of fish to become the ecosystem service of "fishable fish" and thus provide an opportunity for recreational fishing include the aspects of site accessibility (e.g., road access, available parking, presence of a fishing pier) that facilitate fishing at the site and may enhance enjoyment of the activity.
Ecological benefit	In the context of environmental policy and management, the term applies specifically to net improvements in social welfare that result from changes in the quantity or quality of ecosystem goods and services attributable to policy or environmental decisions. Synonymous with "ecosystem-derived benefits" as used in Wainger and Boyd (2009).
Ecological production function	The type, quantity and interactions of natural features required to generate measurable ecological outputs. For example, the biophysical characteristics of a coastal wetland (e.g., flooding regimes, salinity, nutrient concentrations, plant species abundance, prey and predator abundances) can influence the welfare-enhancing output of increased abundance of a population of watchable wading shorebirds (i.e., the ecological output).
Ecosystem goods and services	Outputs of ecological processes that directly ("final ecosystem service," see Boyd and Banzhaf [2007]) or indirectly ("intermediate ecosystem service") contribute to social welfare or have the potential to do so in the future. Some outputs may be bought and sold, but most are not marketed. Often abbreviated as "ecosystem services."
Ecological risk assessment	A science-based process for evaluating the likelihood that adverse ecological effects may occur or are occurring because of exposure to one or more stressors.
Final ecosystem services	Components of nature that are directly enjoyed, consumed or used to yield human well-being.

Table 1. Common terminology associated with the ecosystem services concept (continued)

Term	Definition
Human well-being	The condition of humans and society, defined in terms of the basic material and natural resource needs for a good life, freedom and choice, health, wealth, social relations and personal security. In economics, the term often is used interchangeably with utility. The definition provided here is broader than the standard economic definition.
Intermediate ecosystem services	Components of nature that are not directly enjoyed, consumed or used to yield human well-being but are important for the production of final ecosystem services.
Natural capital	An extension of the economic concept of capital (i.e., manufactured means of production) to ecosystem goods and services. Natural capital is the stock of natural ecosystems that yields a flow of valuable ecosystem goods or services into the future.
Nonuse value	The value people hold for a service that they do not use in any tangible way. Sometimes referred to as "passive use value." Early literature in environmental economics split nonuse value into three components: existence value, option value and bequest value. Nonuse values are theoretically distinct from use values, but the boundary between use and nonuse values often is ill defined.
Tradeoff	Generally, an exchange of one thing in return for another, especially relinquishment of one benefit or advantage for another. In a decision-making context, it applies to the goods and services (including but not limited to ecosystem goods and services) gained or lost as the result of a management choice.
Use value	The value of a good or service derived from its direct or indirect use (see nonuse value).
Valuation	The process of estimating the worth, merit or desirability of something. Specifically with respect to ecological benefits, it refers to the quantification of those benefits.
Value	The worth, merit or desirability of something assessed in terms of how much of one good or service a person is willing to give up to gain more of another good or service. It can be expressed quantitatively (e.g., in monetary terms) or qualitatively.

Source: Munns et al. (2015).

The concept of value in relation to ecosystem services should be considered in its broadest sense. Value can encompass economic and intrinsic worth (MEA 2005; SAB 2009). Economic value generally is based on the concept of individual welfare and individual preferences. See Text Box 3 for an alternative valuation approach. It includes use and nonuse values of market goods (e.g., fish and forest products) and nonmarket goods (e.g., recreational fishing opportunity). Use values derive from the direct or indirect use of ecosystems and their services.

Text Box 3. Receiver- Versus Donor-Based Valuation Methods

Economic valuation methods are grounded in concepts of human utility, providing information about the value of changes in ecosystem services as held by the beneficiaries (receivers) of those services—human society. EPA's Science Advisory Board Committee on Valuing and Protecting Ecological Systems and Services (SAB 2009) and others encouraged EPA to develop donor-based methods of valuation to supplement economic approaches. Donor-based approaches—often based on an analysis of the stocks and flows of energy—use biophysical accounting methods that provide alternative perspectives on nature's worth and sustainability. These latter methods do not rely on, nor consider overtly, the values of people.

Nonuse values can include knowledge of an ecosystem's existence and certain values related to cultural and religious beliefs. Conversely, intrinsic values are nonutilitarian and can relate to ethical and moral beliefs (Text Box 4).

Ecosystem service valuation methods attempt to estimate the values quantitatively or qualitatively that people ascribe to changes in ecosystem services. Some approaches estimate monetary value, yet monetization is not the only way to describe the value of changes in ecosystem services. In the context of national rulemaking and other decision-making processes, EPA might conduct economic assessments of the consequences of regulatory actions or other environmental policies. These might be specified by statutory requirement or Executive Order (e.g., Executive Order 12,866[8]) or simply might be desired as part of an environmental management approach. Although monetization provides a useful and convenient common denominator for comparing the tradeoffs involved with various policy options, some changes in ecosystem services might lend themselves only to nonmonetary quantitative or qualitative assessment. Quantitative and qualitative measures of valuation provide useful information on the ecosystem services that people value that should not be overlooked. Other, noneconomic approaches to valuing ecosystem services also can provide an indication of the value of changes in ecosystem services. For instance, biophysical measures, such as the number of acres restored, might be used to quantify the amount of ecosystem services restored (SAB 2009) (see Text Box 3).

When multiple ecosystem services are to be considered in a risk assessment, valuation conveys the important advantage of supplying common units, monetary or nonmonetary, to changes in risk to those ecosystem services. Ideally, these values can be aggregated across ecosystem services to derive a total value for the ecological benefits derived under a particular decision scenario. As an example, an assessment of risk to wetlands from herbicide use could take into account the values associated with changes in the wetland's contributions to flood stage reduction, water purification and fishery production. The final accounting would include the total value of the ecosystem service changes.

Good decision making involves comparison of the projected outcomes of policies and choices. Tools such as benefit-cost analysis facilitate these comparisons (see the discussion of Executive Order 12,866 in Section 2.3). Benefit-cost analysis is a formal quantitative (and sometimes qualitative) evaluation of the benefits to be derived from a decision or action compared to the costs incurred by implementing that decision or action. Benefits and costs can include market values and nonmarket values. The general approach in benefit-cost analysis is to estimate policy impacts in comparable terms that enable evaluation of the net effects of a policy. For ease of comparison, an attempt is made to monetize benefits and costs to

[8] 58 *Fed. Reg.* 51735 (Sept. 30, 1993).

the extent possible, but often ecological benefits in particular are described quantitatively or qualitatively in terms other than money (USOMB 2003b). Although considered in the decision-making process, ecological benefits that are not monetized cannot be incorporated easily into strict calculations of the net benefits associated with various decision alternatives (USOMB 2003a). The Agency's expectations for

Text Box 4. Nonuse and Intrinsic Values

Nonuse values describe values people have for an ecosystem service that they do not directly or indirectly use but view as affecting their well-being. Nonuse values can be quantified using neoclassical environmental economic techniques such as stated preference surveys (see Appendix A). Examples of nonuse values include:

- Habitat preservation.
- Existence value for threatened and endangered species.
- Bequest value (e.g., wilderness areas set aside for future generations).

The concept of intrinsic value considers the possibility that a component of nature has value even if it does not confer benefits directly or indirectly to humans. Although nonuse values can be quantified from an anthropocentric perspective, intrinsic values are quantified from a biocentric (or ecocentric) one. Donor-based valuation methods notwithstanding (see Text Box 3), no generally accepted methods exist by which the values held by ecosystems can be elicited. This renders the biocentric perspective somewhat problematic for informing environmental decisions that can affect broad segments of society. Ironically, when people express a desire to base decisions affecting particular ecosystems (or components thereof) on intrinsic values, they sometimes are reflecting their own (anthropocentric) nonuse existence values for those ecosystems (Goulder and Kennedy 2011).

conducting benefit-cost and other economic analyses are laid out in its *Guidelines for Preparing Economic Analyses* (USEPA 2014), and the reader should refer to those Guidelines for acceptable practices in calculating economic values. While other approaches to valuation may be useful for some purposes, OMB's Circular A4 (USOMB 2003b) specifies that only willingness-to-pay-based approaches to valuation, such as those identified in the Guidelines, may be employed in benefit-cost analyses.

2.3. Legal and Statutory Authority

Some of EPA's current statutory and regulatory mandates, as well as executive orders, can be interpreted to incorporate the concept of ecosystem services into the decision-making process, whereas others neither encourage nor prohibit the concept. The following examples illustrate that diversity of mandates.

- **Executive Order 12866.** Executive Order 12866, issued in 1993, 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). Implementation of this Executive Order at EPA has been impacted by a limited ability to account for the value of changes in ecosystem services and the costs associated with ecosystem service losses or gains. Thus, tools that can help account for changes in ecosystem services will benefit the EPA program offices responsible for implementing Executive Order 12866. EPA developed a strategy to improve its ability to quantify the ecological benefits of its policies and actions to help develop these tools (USEPA 2006).

- **Clean Water Act.[9]** The CWA contains numerous provisions that give EPA authority to conduct research and regulate discharges of pollutants that may impact aquatic resources. Actions taken

[9] 33 U.S.C. § 1251 et seq.

pursuant to these provisions could result in protecting ecosystem services. There are also provisions in the CWA that recognize there may be the use or exploitation of aquatic ecosystem services. These different provisions may reflect competing objectives of the major 1972 amendments to the CWA and subsequent amendments. For example, the goals and policy of the

Text Box 5. Ecology and Economics

What are our planet's life-support services worth? Because many critical ecosystem services do not have market value or cannot be quantified readily using existing economic tools, most are assigned a value of zero in risk assessment and decision making. In one of the first efforts to provide a global quantification of all ecosystem services, Costanza et al. (1997) valued Earth's life-support systems at $33 trillion per year. This effort has been criticized by economists as a "serious underestimate of infinity" (Toman 1998). He argues that asking about the value that we would lose if an entire and irreplaceable life-support system were lost will never make sense. His point is that if the system truly were for life support, its loss would lead to the end of all human life; therefore, to put an economic value on that loss seems foolish and inappropriate. Yet, we currently place no value on these systems.

In planning, conducting and communicating ERA, it is critical for ecologists and biologists to inform and educate economists, decision makers and the public on the value of the essential structural and functional aspects of all ecosystems in which we live and upon which we depend for survival. All ecosystem structural and functional characteristics are important to varying degrees for maintaining life, as we know it on this planet, including our own lives.

Too often, society places value only on those ecosystem services that are translated readily into some measure of economic, religious or social worth. Yet biologists, ecologists and others understand that this is only a partial accounting and that society needs to value all the life-supporting features of Earth. Even the rich biodiversity of the benthic fauna in the mud of an estuary is critical to the survival of life on Earth. Just as critical is a small intermittent suburban headwater stream in a natural wooded area. Their values to life may not be readily apparent to the layperson, politician or economist. Their value may not be immediate, and economists currently do not know how to place dollar values on them, yet it is known that such seemingly benign features of the environment are critical building blocks—the essential elements of the web of life.

CWA, as described in Section 101, include to "restore and maintain the chemical, physical and biological (or ecological) integrity of the Nation's waters." It also is the national goal of the CWA to eliminate the discharge of pollutants into navigable waters and prohibit the discharge of toxic pollutants. These are high standards that when fully implemented will lead to a high level of protection of aquatic resources and their ecosystem services.

CWA Section 101 also states that "it is a national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish and wildlife, and provides for recreation in and on the water be achieved ..." Section 402 of the CWA, however, allows EPA or an authorized state to issue permits allowing the discharge of pollutants to waters of the United States.

Section 404 of the CWA covers permits for the dredging and filling of water bodies and requires that EPA issue guidance on procedures for evaluating and mitigating adverse environmental impacts to wetlands that result from projects receiving federal aid. The presumption is, however, that some dredging and filling of aquatic ecosystems, and the loss of ecosystem services, is allowable if the effects will not be significantly adverse as determined by risk assessment.

The CWA contains no mandate for benefit-cost analysis or for enumeration of ecosystem goods, services or benefits. Analysis of ecosystem services, however, may supplement analyses of biotic integrity, fish, shellfish and other resources.

- **Clean Air Act (CAA).[10]** The CAA provides protection from “known or anticipated adverse effects to public welfare” via secondary National Ambient Air Quality Standards (NAAQS). According to Section 302(h), welfare effects include but are not limited to “effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property and hazards to transportation, as well as effects on economic values and on personal comfort and well-being whether caused by transformation, conversion or combination with other air pollutants.” The current secondary NAAQS reviews for oxides of nitrogen and sulfur (NO_x and SO_x), ozone and particulate matter are all evaluating the use of ecosystem services to assess adverse effects to public welfare.

- **National Environmental Policy Act (NEPA).[11]** The Council on Environmental Quality’s (CEQ) implementing regulations for NEPA[12] define effects and impacts (used synonymously) of responsible agency actions to include “ecological (such as the effects on natural resources and on the components, structures and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative.”[13] CEQ also provides considerations for incorporating effects on biodiversity in environmental impact analyses (CEQ 1993). Although neither NEPA nor CEQ’s regulations explicitly use the term ecosystem services, which came into common usage after NEPA was enacted, the types of effects considered under NEPA are consistent with the concept of ecosystem services employed here. The regulations also allow comparisons of the impact of proposed actions to be appended (or incorporated by reference) to inform decisions. The regulations stipulate, however, that, “for purposes of complying with the Act, the weighing of the merits and drawbacks of the various alternatives need not be displayed in a monetary benefit-cost analysis and should not be when there are important qualitative considerations.”[14] From EPA’s perspective, improved quantification of ecological benefits in benefit-cost analyses requires consideration of changes in ecosystem services (USEPA 2006).

- **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[15]** The regulations that guide the assessment of natural resource damages under CERCLA provide for compensation for injury to natural resources and the loss of ecological services those resources provide. Natural resource damage assessments (NRDAs) are performed by the natural resource trustees, but the opportunity exists for EPA to coordinate its CERCLA remediation assessments with the trustees through informed ERA assessment endpoint selection (Text Box 6).

- **Oil Pollution Act of 1990 (OPA).[16]** The OPA establishes liability for the discharge—and substantial threat of a discharge—of oil to navigable waters and shorelines. A major goal of the OPA is to restore the natural resources and services that are lost because of oil spills. The responsibility for acting on behalf of the public lies with designated federal, state, tribal and natural resource trustees. The OPA directs trustees to (1) return injured natural resources and

[10] 42 U.S.C. § 7401 et seq.
[11] 42 U.S.C. § 4321 et seq.
[12] 40 CFR 1500–1508.
[13] 40 CFR 1508.8.
[14] 40 CFR § 1502.23.
[15] 42 U.S.C. § 9601 et seq.
[16] 33 U.S.C. § 2701 et seq.

Text Box 6. Ecosystem Service Assessment Endpoints as a Common Currency for ERA and Natural Resource Damage Assessment

CERCLA provides authority for remediation of contaminated sites and restoration of injured natural resources. Site remediation decisions are informed by ERA, whereas restoration and compensation decisions are informed by the natural resource damage assessment (NDRA) process. The goals of NRDA are to return natural resources injured due to the release of hazardous substances to their uninjured or baseline condition (i.e., the condition prior to the release of hazardous substances) through direct restoration or replacement of injured resources, and to compensate the public for ecosystem service losses occurring until those injured resources are restored. Ecological injuries are quantified in terms of the reduction in the physical, chemical or biological ecosystem services that the natural resources provide. Compensation for those injuries is claimed in terms of damages (monetary) or directly as restoration actions. Damages are calculated using various market and nonmarket economic techniques. Damages and direct restoration projects are scaled to the magnitude of the injury claim. The objectives for ERA conducted under CERCLA and similar state statutes are to identify and characterize the current and potential threats to the environment from a hazardous substance release and identify cleanup levels that would protect those natural resources from additional adverse effects (USEPA 1997).

The intention of Superfund ERA is to provide information about contamination risk to societally relevant assessment endpoints (e.g., the abundance of small mammal populations). In practice, however, the relationships among ERA assessment endpoints and valued ecosystem services often go unstated. Further, insufficient attention has been given to the relationships between measures of effect and ecosystem services that would facilitate straightforward translation of adverse ecological effects to ecosystem service losses in NRDA. Recognition and selection of ecological assessment endpoints that explicitly and more directly reflect ecosystem services should improve the value of ERA data to the NRDA process and likely will improve the societal relevance of ERA conclusions to remediation decisions.

Source: Adapted from Munns et al. (2009).

services to the condition they would have been in if the incident had not occurred; and (2) recover compensation for interim losses of such natural resources and services through the restoration, rehabilitation, replacement or acquisition of equivalent natural resources or services. Similar to Agency actions under CERCLA, informed assessment endpoint selection in Agency ERAs would complement EPA's OPA activities with those of the trustees (Text Box 7).

- **Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).[17]** FIFRA Section 3(a) stipulates, "[t]o the extent necessary to prevent unreasonable adverse effects on the environment, the Administrator may by regulation, limit the distribution, sale, or use in any State of any pesticide that is not registered under this subchapter." FIFRA gives the Agency authority to regulate the sale and use of pesticides through registration and labeling. Registration includes submission of required data by the producers/registrant, evaluation and acceptance of these data by EPA, submission of a proposed label, review and acceptance of the final labeling by EPA, establishment of a tolerance (maximum residue level) for pesticides used on food or feed commodities and classification by EPA of the pesticide product for restricted or general use. Under FIFRA, EPA must find that exposure of environmental systems to the pesticide does not cause "unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide."[18] This requirement provides an opportunity to consider ecosystem services in the risk assessment process.

[17] 7 U.S.C. § 136 et seq.
[18] 7 U.S.C. § 136, as the definition of "Unreasonable adverse effects on the environment"

Text Box 7. Ecosystem Services Associated with the Deepwater Horizon Oil Spill

The Deepwater Horizon (DWH) oil spill was the largest environmental disaster and response effort in U.S. history, with more than 507 million liters of crude oil spilled during a 3-month period. Vast areas of the Gulf of Mexico were contaminated with oil, involving deep ocean communities, protected species, more than 1600 km of oiled shoreline and more than 20 million hectares closed to fishing (Carriger and Barron 2011). Losses of ecosystem services from the DWH spill include reductions in commerical and recreational fishing and tourism (Carriger and Barron 2011), which are being quantified through the ongoing NRDA process and a National Academy of Sciences Ocean Studies Board project. Many of the largest impacts from the DWH (e.g., fishery closures, loss of ecosystem services from oiled wetlands and beaches) are not considered in typical ecological and human health risk assessments (Cairns and Niederlehner 1994; Jordan et al. 2010; MEA 2005; Munns et al. 2009). Coastal wetlands, however, aid in flood control and storm surge reduction; improve water quality by sequestering and transforming pollutants; provide important carbon sequestration and storage values contributing to a stable climate; and provide critical habitat for fish, shellfish and wildlife. Ocean beaches and barrier islands not only support tourism and recreation and provide important storm and erosion benefits, but also provide habitat for the unique plant and animal communities that are essential for maintaining sea turtle populations and other protected species.Four federal agencies (the U.S. Departments of Commerce, Interior, and Agriculture, and EPA) and the five affected states are co-trustees and members of the Trustee Council in the DWH spill NRDA. The Department of Defense is also a trustee, but does not serve on the Trustee Council. As of January 2011, NRDA teams had collected nearly 30,000 samples—including water, sediment, soil, tissue, tar balls and oil—and had surveyed nearly 7,000 km of shoreline (NOAA 2011). Observed impacts included oiled wildlife (e.g., 4,300 birds and 450 sea turtles) and more than 1,600 km of oiled shoreline (NOAA 2011). Evaluating the losses of ecosystem services in the Gulf of Mexico will require identifying the specific services that have been affected and the interrelationships among service losses. For example, many human activities may have changed in response to the spill and also changed the balance of ecosystem services in the region (NAS 2011). Specific aspects of quantifying service losses from the DHW spill will include determining the (1) ecosystem services provided in the various regions of the Gulf of Mexico ecosystem prior to the spill; (2) appropriate

In addition, several statutes, including the Toxic Substances Control Act and the Resource Conservation and Recovery Act, either directly or indirectly authorize EPA to conduct research that ultimately can be related to protecting ecosystem services. Although these statutes predate the current use of the term "ecosystem services," they support the concept of protecting ecosystem services by protecting ecosystem structure and processes for their benefit to humans. Ruhl et al. (2007) provide a useful overview of the law and policy of ecosystem services.

2.4. Use of the Ecosystem Services Concept by Other Organizations

Even before release of the *Millennium Ecosystem Assessment* (MEA 2005), many governmental and nongovernmental organizations had embraced the ecosystem services concept in their operations. Federal agencies in the United States, such as the U.S. Department of the Interior and the U.S. Department of Agriculture, have initiated programs to evaluate the utility of ecosystem services in terms of policy needs, potential markets and how best to advance the science of ecosystem services, and more broadly, sustainability. For example, the U.S. Forest Service routinely considers ecosystem services and their benefits to people and society in policy making and resource allocation decisions (Kline and Mazzotta 2012; Kline et al. 2009, 2013). Natural resource trustee agencies, including the U.S. Fish and Wildlife Service and the National Oceanic and Atmospheric Administration, consider the services lost because of natural resource injuries at hazardous waste sites during the NRDA process (see Munns et al. 2009). Similarly, the U.S. Army Corps of Engineers and EPA jointly published final regulations in 2008 for procedures authorizing compensatory mitigation of impacts to aquatic resources that the U.S. Army Corps of Engineers permits under Section 404 of the CWA, which requires consideration of ecosystem services in mitigation decisions. The National Ecosystem Services Partnership, a collaboration centered at the Nicholas Institute for Environmental Policy Solutions at Duke University, recently released its *Federal Resource Management and Ecosystem Services Guidebook* (NESP 2015), which describes how ecosystem services can be applied by federal agencies in their practices and decisions. Importantly, an October 7, 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).

Ecosystem services are also reflected in the strategies and decision-informing analyses of the European Union and elsewhere (e.g., EFSA 2010, 2012; EC 2011). The European Commission actively uses the ecosystem services concept to assess the state of natural resources in the member states and provides funding for research projects such as RUBICODE,[19] SOILSERVE[20] and EcoFINDERS,[21] all programs addressing aspects of ecosystem services. The European Union has devoted considerable effort to incorporate ecosystem services concepts in the environmental directives for its member states, such as the Water Framework Directive, Biodiversity Directive and Marine Directive. Australia, Brazil, Russia, China and other countries increasingly are concerned about the status of ecosystem services due to the tremendous demands from the rest of the world for the food, energy sources and minerals available in their countries. The global Economics of Ecosystems and Biodiversity project[22] was established to evaluate the costs of biodiversity loss and associated decline in ecosystem services worldwide. The project has developed into a policy-research community that summarizes and develops concepts and assessment tools and provides guidance on how to use these tools in environmental decision making.

Business and nongovernmental organizations have included ecosystem services in their daily operations. The recognition that businesses depend on and affect ecosystem services has expanded thoughts of environmental performance in facets ranging from product development, life cycle assessments and capital projects to operational resource needs. Business for Social Responsibility,[23] an international network of about 300 member companies, has promoted consideration of ecosystem services in development of sustainable business practices. The organization has described the business case and the available tools for incorporating ecosystem services into corporate strategies (Waage et al. 2008). Groups such the World Wildlife Foundation have launched efforts (e.g., The Natural Capital Project[24]) that focus on ecosystem services as key components of conservation projects and communication strategies. The World Resources Institute developed *Ecosystem Services—A Guide for Decision Makers* (Ranganathan et al. 2008) to help decision makers understand the connectivity between policy goals and ecosystem services and to identify policies that sustain ecosystem services.

Yet despite its increasing acceptance, integration of ecosystem service considerations into environmental management decisions by governments and businesses remains in its infancy. According to the Natural Value Initiative report on the impacts of extractive industries (e.g., mining, timber, oil and gas) on biodiversity and ecosystem services (NVI 2011), that companies recognize they should operate within certain environmental performance parameters, including sustainability, to access resources and grow their businesses is becoming increasingly fundamental. Activities that result in loss of biodiversity or adversely impact ecosystem services affect society's ability to respond to future challenges of water and

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[19] http://www.rubicode.net/rubicode/index.html.

[20] http://www4.lu.se/soil-ecology-group/research/soilservice.

[21] http://ecofinders.dmu.dk/objectives/.

[22] http://www.teebweb.org/.

[23] http://www.bsr.org.

[24] http://worldwildlife.org/projects/the-natural-capital-project.

resource scarcity and climate change. The future of commercial fisheries faces similar challenges. Recent reports by the New Economics Foundation (NEF 2011, 2012) and The Prince's Charities' International Sustainability Unit (ISU 2012) have deemed implementation of an ecosystem approach necessary for sustainable management of this important ecosystem service.

EPA has made significant and innovative advancements in the concepts and science of ecosystem services. The Office of Research and Development's Sustainable and Healthy Communities Research Program and its predecessor, the Ecosystem Services Research Program, have contributed substantially to refining the theory of ecosystem services and have promoted its application through developing and evaluating associated models and tools. In some regards, the Agency's understanding of how ecosystem services can better inform environmental decisions is advanced when compared with agencies in Europe and elsewhere (see, for example, Section 3 of European Food Safety Authority [EFSA 2010]). Augmentation of EPA's ERAs by incorporating ecosystem services as assessment endpoints is a timely and appropriate next step in advancing the Agency's goals with respect to sustainability.

2.5. Advantages of Ecosystem Services as Assessment Endpoints

Ecosystem service assessment endpoints can complement conventional ecological assessment endpoints by offering a systems perspective for clarifying to stakeholders and the public the tradeoffs associated with decision alternatives. By enabling a more complete evaluation of the benefits and costs of decisions, risk managers and decision makers can be informed more fully about the tradeoffs and possible unintended consequences of decision alternatives. Ecosystem service assessment endpoints also can be applied across varying temporal and spatial scales, from local to national assessments. Transparency in decision making is essential, and using ecosystem service assessment endpoints enables clear articulation of the problem being addressed and the alternative solutions being considered.

Specifically, some advantages of using ecosystem service assessment endpoints in ERA are:

- Evaluating risk to a suite of ecosystem services generally supports a more societally relevant assessment than does one that is limited to conventional ecological assessment endpoints.

- Examining multiple ecosystem services in risk assessment reduces the probability of overlooking certain valuable components of an ecosystem and helps avoid unintended environmental consequences of decisions.

- Ecosystem services are translated readily into benefits that society understands and cares about so that the results of risk assessments and the rationales for decisions can be communicated more clearly.

- Some ecosystem service assessment endpoints can be evaluated quantitatively rather than qualitatively or solely in a relative context (i.e., as deviations from reference conditions). Much research during the past several years has been directed (by the Agency and others) toward measuring and modeling the EPFs that link ecosystem attributes to ecosystem services.

- Risks to ecosystem service assessment endpoints can be used as direct input to ecological benefits assessments (USEPA 2006) that support benefit-cost analysis. Good decision making includes comparison of the projected outcomes of alternative policy options. Tools, such as benefit-cost analysis and net benefit analysis, facilitate these comparisons. The general approach in benefit-cost assessment is to estimate the effect of competing options in comparable terms that allow the evaluation of the net effects of a policy. For ease of comparison, an attempt is made to monetize costs and benefits to the extent possible, but often, benefit assessments are incomplete and ecological benefits are described quantitatively or qualitatively in nonmonetary terms.

Use of ecosystem service assessment endpoints also can stimulate and facilitate coordination of decisions across environmental media, agencies, jurisdictions, policies and programs. Text Box 6 (above) discusses how ecosystem service assessment endpoints can inform decisions for the hazardous waste site remediation (a role of the Agency) and restoration (a role of natural resource trustees) required under CERCLA. Similarly, Text Box 7 describes how ecosystem service assessment endpoints could be used to inform the decisions of the multiple agencies responding to the 2010 Deepwater Horizon oil spill in the Gulf of Mexico.

2.6. Selecting Ecosystem Service Assessment Endpoints

Selecting assessment endpoints for evaluation in ERA is a critical and challenging process because of the diversity of species, ecological communities and ecological functions potentially at risk (USEPA 2003). Historically, ecological assessment endpoints have been those that ecologists think are important (such as benthic community diversity), but as noted previously, these endpoints often do not resonate with or have meaning to the broader public. From a societal perspective, assessment endpoints with clear and obvious linkages to human well-being provide a stronger basis for decision making and can aid in communicating assessment results and the ultimate decisions.

The abundance of a recreational fishery species (e.g., winter flounder) that depends on benthic organisms as prey is an assessment endpoint that is likely more highly valued by broad segments of the public than is the benthic community structure of an aquatic ecosystem. In this example, decisions based on risk to winter flounder abundance are therefore more meaningful and transparent to the public than are decisions based solely on risk to benthic community structure. The assessment endpoints conventionally used in ERA often reflect the values of a rather small component of society: ecologists and risk assessors. Selection of ecosystem services to be included in an ERA will require consideration of concepts of societal value, decision context (Text Box 8) and scale.

Text Box 8. Selection of Ecosystem Service Assessment Endpoints Depends on Decision Context

As described briefly in Section 2.3, some of the laws that establish a framework for protecting environmental resources acknowledge and allow for the diminishment of ecosystem services. The CWA is an example of such a statute. Under Section 303, the CWA requires states to develop water quality standards for their waters. States are given the flexibility to develop for their waters water quality standards that consist of designated uses and criteria to protect those uses. In setting designated uses, states can take into account the cost and technical feasibility of restoring or protecting water quality to a specified level. Most states have implemented this provision of the CWA to adopt designated uses for aquatic life that fall short of the CWA ecological integrity goal and acknowledge current degradation that might never be remediated. As a result, some degraded water bodies are designated for activities such as navigation, agricultural and livestock watering or industrial water supply. Uses that are designed to protect the ecological integrity of a water body and therefore the highest level of ecosystem services are not necessarily required for all water bodies.

The Houston Ship Channel, which extends from the San Jacinto River in Harris County, Texas, to a point immediately upstream of Greens Bayou in Harris County, including tidal portions of tributaries (Good Year Creek, Carpenter Bayou, Tucker Bayou, Patrick Bayou and Greens Bayou), is an example. This portion of the water body is designated for navigation and industrial water supply. Along this segment of river are 141 wastewater discharges and 67 industrial stormwater discharges. The criteria adopted to protect this segment's designated use are not adequate to support the existence of aquatic life that would have value for subsistence fishing, fish consumption or commercial fishing. ERAs involving water bodies of this sort will need to recognize that ecosystem service assessment endpoints might differ from those routinely defined for healthier water bodies.

Assessments should consider endpoints that affect human well-being and are valued by people. Ecosystems generally contribute to human well-being through provisioning, regulating, cultural and support services (MEA 2005). People sometimes may not understand the linkage, however, between the ecosystem service and the contribution of that service to their well-being. Without that understanding, some people might not be able to appreciate the implications of ecological risk to their well-being. Ecosystem service valuation is useful for informing and understanding decisions about environmental protection.

A consideration in selecting the ecosystem services appropriate for a particular assessment and decision is scale. Ecological processes and human well-being include temporal and spatial aspects of scale (MEA 2005; de Groot et al. 2002). Using ecosystem service assessment endpoints in risk assessment necessitates accounting for the localities and scales at which (1) specific services are produced, and (2) their benefits are received by society (Table 2). For example, wetlands contribute to the production of several ecosystem services, including clean water, flood control and a stable climate. In each case, the EPF is local to the wetland (although it can be aggregated across wetlands), but the ecological benefits are realized at different spatial and temporal scales. By removing or sequestering pollutants, the wetland may cleanse water to the benefit of aquatic life far downstream (an intermediate ecosystem service), perhaps even in an estuary or the coastal ocean; ecosystem service production generally would be continuous (or seasonal) and long term. The wetland also might mitigate downstream flooding by retaining water and retarding flow. Ecological benefits associated with this service are likely to be more local (less spatially extensive) than are those linked to provisioning of clean water; in the temporal realm, they would be episodic. Finally, by sequestering carbon through photosynthesis and soil accumulation, the wetland contributes to a stable climate. The benefits of this service are global and very long term, although they can vary spatially and temporally worldwide. Identifying the appropriate scales of production for ecosystem services is a task for ecologists; identifying the beneficiaries and scales of ecosystem services provision is a multidisciplinary task involving economists and other social scientists, engineers, ecological modelers and others. By combining these disciplines through an ecosystem services lens, decisions can be made using more complete information, lessening the unintended consequences of those decisions.

Guidelines and criteria for selecting assessment endpoints generally are provided by EPA (USEPA 1998). Further, EPA's GEAE guidelines (USEPA 2003) describe how GEAEs can be considered during the selection process. Ringold et al. (2009) have proposed six steps for identifying ecosystem services as assessment endpoints on an assessment-specific basis:

1. Clearly understand the decision to be informed, the decision context and the informational needs of the people making the decision. In particular, determine whether ecological benefits should be quantified to help inform decisions (e.g., for a benefit-cost analysis).

2. Understand the kinds of information needed most critically to inform selection among decision alternatives based on policy- and management-relevant changes in final ecosystem services or other assessment endpoints.

3. Create conceptual models describing the EPFs producing policy- and management-relevant final ecosystem services.

4. Identify a manageable suite of candidate measures of effect of final ecosystem services from the conceptual models that can inform the decision and evaluate them against the factors listed in Text Box 9. Select the final suite of measures that facilitates evaluations of decision tradeoffs from a systems perspective.

5. Use the conceptual models to create verbal and visual representations of the relationships between each measure and the final ecosystem services (and ecological benefits) to which they link. To clarify these relationships, conceptual models might be augmented by mechanistic or process models when needed.

6. Define the units of measurement explicitly for each measure of effect, including consideration of the spatial and temporal scales over which they will be measured.

Table 2. Classification of ecosystem services by spatial characteristics of their production

Service Class	Class Attributes	Example Ecosystem Services*
Global/non proximal	Benefit does not depend on proximity of service	• Stable climate • Genetic resources for biotechnology
Local/proximal	Benefit depends on proximity of service	• Disturbance regulation • Storm protection • Waste treatment • Pollination • Biological control
Directional flow related	Benefit received at points downstream of services production	• Flood protection • Water supply

In situ	Benefit received at point of service production	• Soil production
User movement related	Benefit received by people and flows to point of service production	• Recreational opportunities • Cultural and aesthetic opportunities
Local/extensive	Benefit produced locally, delivered regionally or more widely	• Food production (e.g., crops, fisheries)

*Includes final and intermediate ecosystem services.
Source: Adapted from Costanza (2008).

Text Box 9. Evaluation Factors for Selecting Measurement Endpoints or Indicators of Final Ecosystem Services

- They can be quantified in biophysical units.
- Decision makers/stakeholders have been involved with and agree to their selection.
- The suite of indicators includes those most needed to inform the decision and represents an array of ecosystem services to facilitate evaluations of tradeoffs from a systems perspective.
- The scale and intensity of their measurement best match those needed to inform the decision.
- Their measurement and evaluation can be completed in the timeframe needed to inform the decision.
- They are easily interpreted by nonscientists to facilitate valuation.

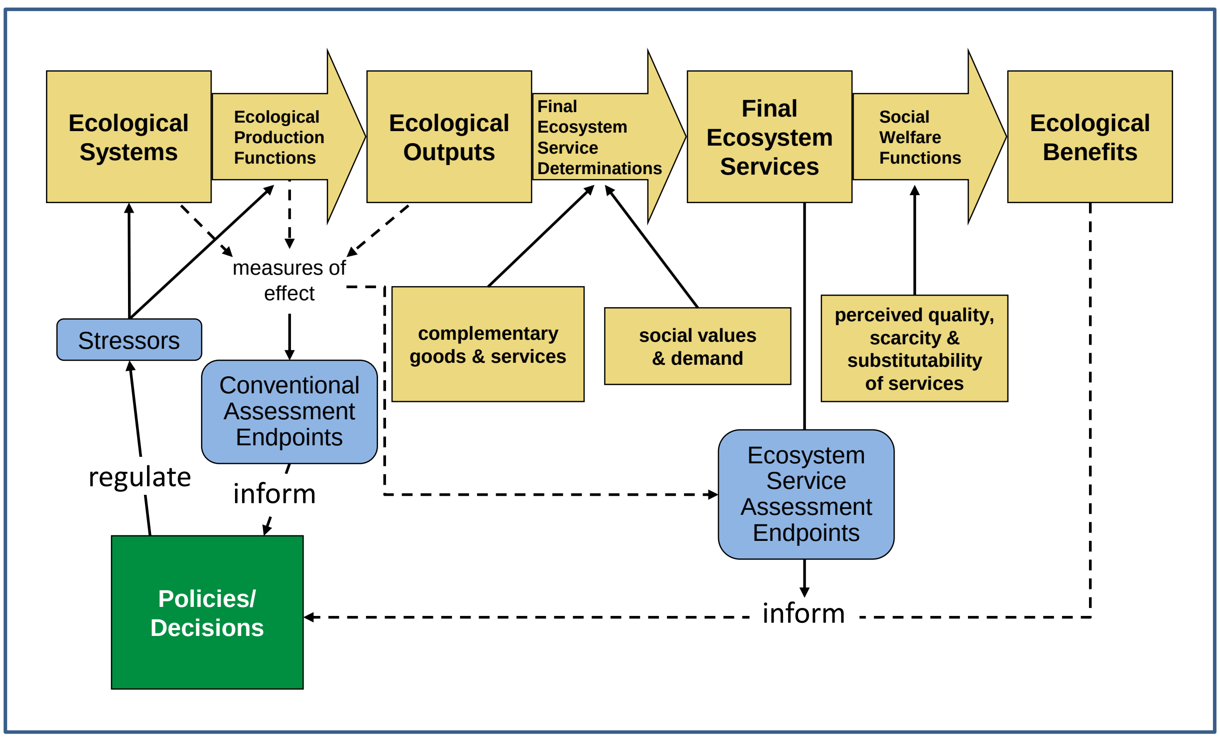
Source: Adapted from Ringold et al. (2009).

Section 3: Linking Conventional Assessment Endpoints and Measures of Effect to Ecosystem Service Assessment Endpoints

3.1. Ecological Production of Ecosystem Services

Ecosystems produce ecological outputs, including goods and services, by means of ecological production functions (EPFs). Conventional assessment endpoints and measures of effect typically are components of EPFs such that quantitative changes in these endpoints influence the ecological outputs of EPFs. For example, a forest accumulates biomass and sequesters carbon through the complex processes of plant growth and soil formation, which involve sunlight, photosynthesis, microbial metabolism, physical factors, climate and precipitation. Conventional assessment endpoints and measures of effect, such as plant species and age diversity, play key roles in the EPFs for final ecosystems services, for example, timber for construction and fuel for cooking and heating. The types and qualities of EPFs depend on the structure and condition of the ecosystem, so that an ecosystem under pressure from stressors (e.g., a forest weakened by air pollution and soil acidification) might have diminished capacity to help create a stable climate (by storing carbon), grow timber or maintain soil production. Stressor-induced changes in EPFs affect ecological benefits when the outputs of these functions are ecosystem services. Figure 2, which expands on the conceptualization in Figure 1, makes more explicit the relationships of stressors and conventional endpoints. A key technical requirement of a risk assessment incorporating ecosystem services is to understand (through modeling or measurement) the ecological production of the outputs considered to be ecosystem services and determine the measures of ecosystem processes and conditions that are essential for describing that production.

Figure 2. Conceptualization of the relationships between ecosystem services and conventional assessment endpoints



3.2. Measures of Effect — Ecosystem State, Processes and Outputs

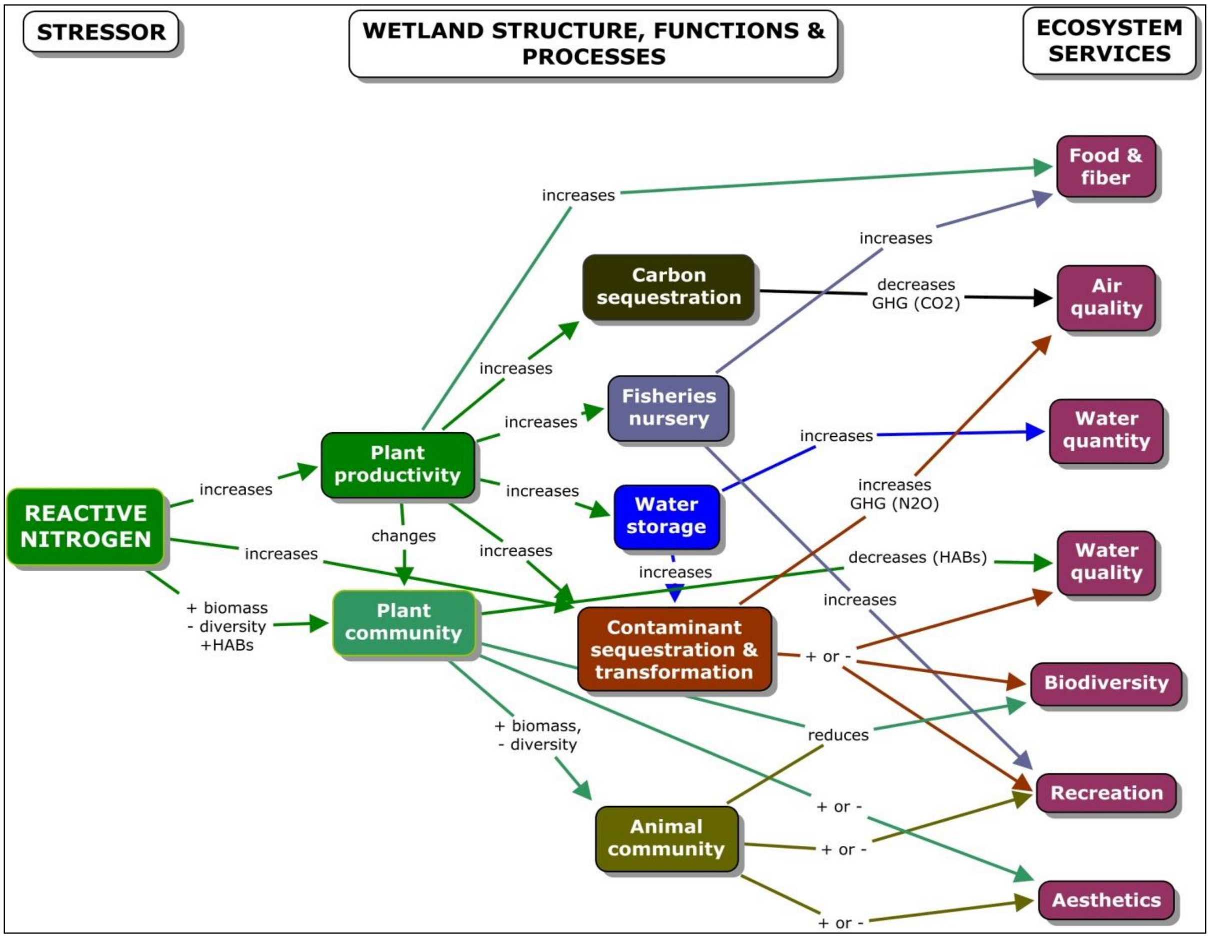
As noted previously, measures of effect may substitute as proxies for assessment endpoints in an ERA. Measuring all the properties and processes of an ecosystem that contribute directly or indirectly to human well-being is impossible. Therefore, observation, theory and modeling are employed to identify measures that support inferences about ecosystem condition, processes and, ultimately, services. For example, an impaired stream ecosystem might display a low diversity of aquatic invertebrates and even be dominated by a single functional group such as filter feeders. From measures of the invertebrate community, one could infer that some ecological processes (e.g., shredding, predation) are impaired or have been lost and that the stream has shifted from a detritus-based to a plankton-based ecosystem. By further inference, one might predict impairment of a recreational fishery population, an ecosystem output valued and enjoyed by people (i.e., a final ecosystem service). Diversity of macroinvertebrates might be a conventional assessment endpoint employed in an ERA informing decisions about that stream, but its social value would not be understood readily by most people. Still, diversity of macroinvertebrates could be an informative measure of effect used as a proxy for the ecosystem service assessment endpoint of recreational fishery population abundance, given an adequate understanding of the EPF yielding that population. This relationship is not shown in Figure 2. Similarly, ecological outputs can serve as proxies for conventional assessment endpoints and those based on ecosystem services. This example illustrates the necessary chain of inference that can introduce additional uncertainty into assessment results and is a potential disadvantage of ecosystem assessment endpoints. A remedy is to develop validated models of the relationships among ecological measures, ecosystem services and ecological benefits such that these relationships can be understood with increased confidence. Because measures of effect linked to ecological outputs require less extrapolation to relate to ecosystem services (Figure 2), those relationships can be described with greater confidence.

Figure 3 illustrates the relationships between a stressor (reactive nitrogen) and the state, processes and ecosystem services of a wetland ecosystem. In this example, plant and animal community biomass and diversity are typical conventional measures of the state or condition of this ecosystem. Plant productivity, carbon sequestration, water storage, fisheries nursery and contaminant processing are ecological processes (and potentially, intermediate ecosystem services). Collectively, these wetland structures and processes produce the ecosystem services shown at the far right of Figure 3. Although ecosystems are complex, many of these relationships are known with reasonable confidence; therefore, only a few measures might be needed to evaluate risks to ecosystem services. In the case of the effects of nitrogen loading on an air quality ecosystem service, the effects of nitrogen loading on plant productivity generally are predictable as is the relationship between plant production and carbon storage, the effects of carbon as CO_2 on greenhouse gas emissions and the impacts of greenhouse gases on climate change. Changes in plant growth or biomass might be indicative of changes in the air quality ecosystem service when interpreted through models of nitrogen loading and greenhouse gas emissions (Figure 3).

3.3. Linking Conventional Assessment Endpoints to Ecosystem Services

Assessment endpoints are explicit expressions of the environmental values to be protected (USEPA 1998). As such, conventional assessment endpoints represent components of nature that society and stakeholders find desirable and that merit consideration during the environmental decision-making process (USEPA 2003). Typically, however, the connections between assessment endpoints used in Agency ERAs and ecosystem services have been implicit at best. The relationships between risk to conventional assessment endpoints and their meaning with respect to social welfare have received little direct attention in the assessment and decision-making processes. A clear exception is illustrated by the case study of secondary air quality standards for oxides of nitrogen and sulfur summarized in Section 5.2 and detailed in Appendix B. As dictated by the Clean Air Act, the assessment and decision were based largely on considerations of public welfare.

Figure 3. Relationships among a stressor (reactive nitrogen), ecosystem structures, ecosystem processes and ecosystem services of wetlands



Note: Multiple ecosystem services might be affected positively or negatively by a single stressor.
Key: HABs = harmful algal blooms; GHG = greenhouse gases.

Conventional assessment endpoints can be related to ecosystem services even when the latter were not considered explicitly during assessment scoping activities. By using the relationships presented in Figures 1 and 2 and acknowledging the values that stakeholders and society hold for ecosystems and their outputs, many conventional assessment endpoints likely can be linked, at least conceptually, to ecological benefits. Implicit in endpoint selection are social values (the values held by people for components of the environment), whether consciously expressed or not. Using assessment endpoints that are linked closely to ecological benefits through ecosystem services helps maximize the value of assessment results for decision making. When assessment endpoints do not relate obviously and directly to ecosystem services and associated ecological benefits, however, EPFs can be used to develop the association. As noted above, extending the chain of inference between that which is measured and the selected assessment endpoint creates additional uncertainty about how well the assessment addresses key risk management concerns. Important considerations when selecting ecosystem service assessment endpoints during assessment planning and problem formulation are described in Section 2.5.

The relationship between conventional ecological assessment endpoints and ecosystem service assessment endpoints can be illustrated as follows. In the fisheries nursery consideration presented in Figure 3, the conventional ecological assessment endpoint might be associated most commonly with some articulation of resource abundance. The distinction between this and an ecosystem service assessment endpoint might seem trivial, yet specification of the relevant ecosystem service assessment endpoint would consider not just how many fish there are, but also how many fish are available to be caught recreationally or harvested commercially. Conventionally, Agency ERAs purposefully have considered risks to things like resource abundance, but have not extended considerations to the specific benefits those resources might confer to society. Changes in the abundance of the stock (an ecological output) can be translated into an ecosystem service by taking into account the demand and opportunity to catch the fish, that is, the inputs to final ecosystem services shown in Figures 1 and 2. Several factors might determine fishing opportunity, including the location and accessibility of the water body, type of gear used to catch the fish and regulations that control harvest, among others. With the use of appropriate models and methods, changes in the ecological output (harvestable fish) can (1) be assessed based on scenarios of environmental change or related to policy options that affect ecosystems, and (2) be translated into ecological benefits by understanding economic or other social values. For recreational fisheries, monetary estimates of ecological benefits can be made from the expenditures that fishers make for the opportunity to catch the fish or other methods described in Appendix A. Commercial fisheries have a direct market value that can be used as an indicator of benefit, although the realized ecological benefit involves other considerations, such as the net income to fishers after accounting for their costs; the value added in retail markets; and nutritional, cultural and existence values. Similar considerations are appropriate for other ecosystem service assessment endpoints.

This example illustrates that assessing risks to ecosystem service assessment endpoints might require more information than conventional approaches focusing on ecosystem properties and outputs. For example, estimating risk to a fishery ecosystem service caused by a stressor can involve rather complex modeling that employs a variety of observational data from fishery-dependent, fishery-independent and environmental monitoring and information from research studies and theory. Despite the possible burden of added analysis, the ecosystem services approach may be the best option for demonstrating the ecological benefits that decisions affecting ecosystems provide to society. Jordan et al. (2009, 2012) provide concrete examples of predicting fishery ecosystem services from the quality and extent of estuarine habitats.

The final set of assessment endpoints for a given ERA likely will not be limited solely to ecosystem service assessment endpoints, particularly to those involving final ecosystem services. Many components of nature contribute to sustainable ecosystems and societies in addition to those that benefit people directly. Further, conventional assessment endpoints are are included in all EPA ERAs and are sufficient for many of them. They are included because they represent the ecologically important and susceptible entities and attributes that are protected by U.S. laws and the regulations informed by ERA. The two types of assessment endpoints should be viewed as being complementary, yet as providing different kinds of information to the decision-making process.

Section 4. Enhancing Generic Ecological Assessment Endpoints

4.1. Generic Ecological Assessment Endpoints

In ERA, assessment endpoints should be selected based on three criteria: (1) their ecological relevance, (2) their susceptibility to stressors of concern and (3) their relevance to management goals. As described in Section 1.2, EPA developed a set of GEAEs to be considered and adapted as appropriate to specific ERAs (USEPA 2003). The range of these GEAEs includes organismal-, population-, community- and ecosystem-level endpoints and officially designated endpoints such as critical habitat for protected species. Explicit consideration of ecosystem services enhances the use of GEAEs in meeting the needs of specific assessments and decision contexts.

The establishment of these GEAEs also considered the types of values associated with assessment endpoints (e.g., provisioning, functional, recreational, existence) that benefit society. Although ecosystem services were not addressed explicitly in the first edition the GEAE, the generic endpoint selection process considered issues closely tied to the connections among assessment endpoints, ecosystem services and ecological benefits. For example, generic endpoints describing assessment populations (such as a recreational fishery) can be related easily to ecosystem services that link to recreational or provisioning benefits.

4.2. Incorporating Ecosystem Services

That ecosystems and their functions are valuable to humans is widely recognized. The first edition of the GEAEs explicitly outlines in qualitative terms how GEAEs are related to environmental values (USEPA 2003, Table B-1). Proposing ecosystem services as assessment endpoints is a step forward in that these endpoints can be described in terms that society can appreciate and value readily. The ecosystem service approach complements and enhances conventional ERA endpoints, and its adoption as a type of assessment endpoint is intended to augment and improve the value of ERA in environmental decision making.

Table 3 illustrates the relationships among conventional ecological assessment endpoints (USEPA 2003), generic ecological assessment endpoints (GEAEs), and generic ecosystem service assessment endpoints. Included are considerations of some likely ecological benefits associated with changes in the ecosystem service, as well as valuation methods that might be used to quantify those benefits (see also Appendix A). In addition to drawing connections between established GEAEs and generalized ecosystem services, this table could be used as a basis for identifying additional GEAEs by considering ecosystem services and ecological benefits.

The example generic ecosystem service assessment endpoints presented in Table 3 reflect both final (direct) and intermediate (indirect) ecosystem services. As discussed in Section 2, linkages between ecosystem services and ecological benefits are strongest when final ecosystem services are considered, because they require less translation to ecological benefits. Whether an ecosystem service is deemed intermediate or final is largely a matter of the perspective of the beneficiary and the decision context (Boyd and Banzhaf 2007). Including intermediate ecosystem services in an expanded discussion of GEAEs can help clarify the relationships among conventional ecological assessment endpoints, GEAEs and ecosystem services.

Table 3. Examples of the relationships among conventional ecological assessment endpoints, GEAEs, generic ecosystem service assessment endpoints, ecological benefits and valuation

Conventional Ecological Assessment Endpoint	GEAE	Possible Generic Ecosystem Service Assessment Endpoint	Ecological Benefit	Potential Valuation Methods
• Population abundance • Population size structure • Recruitment • Presence/absence of game species • Mortality, morbidity or survival • Tissue contaminants • Growth, production or extirpation • Taxa richness	• Population abundance and production	• Food production (e.g., catchable, edible fish for recreational, commercial and subsistence uses)—a final ecosystem service	• Nutrition • Recreation • Income • Enjoyment of catching/preparing food • Survival	• Market value and rents for commercial fisheries • Recreational demand modeling • Stated preference • Household production
• Ecosystem functions (e.g., nutrient and flood water retention, organic matter degradation)	• Ecosystem function	• Water purification for drinking, domestic, industrial and agricultural uses—a final ecosystem service	• Support for life, health and commerce	• Extraction and treatment costs • Water rights trading values • Stated Preference • Hedonic values for industry and agriculture production
• Plant community uptake and deposition of pollutants	• Ecosystem function	• Air purification (for breathing and visibility)—a final ecosystem service	• Support for life and health	• Pollution control costs • Stated preference • Replacement cost

Table 3. Examples of the relationships among conventional ecological assessment endpoints, GEAEs, generic ecosystem service assessment endpoints, ecological benefits and valuation (continued)

Conventional Ecological Assessment Endpoint	GEAE	Possible Generic Ecosystem Service Assessment Endpoint	Ecological Benefit	Potential Valuation Methods
• Plant community net production • Carbon sequestration	• Ecosystem function	• Climate stabilization—a final ecosystem service	• Support for life and health	• Greenhouse gas control avoided costs (or damages) • Stated preference • Benefits transfer
• Water retention	• Ecosystem function	• Flood and storm surge regulation—a final ecosystem service	• Protection of life and property	• Avoided damage costs of flooding • Hedonic (Insurance or costs of structural mitigation) • Replacement cost
• Yellow pine production • Standing biomass of trees • Cotton production	• Population abundance and production • Assemblage production	• Raw material production—a final ecosystem service	• Support for life • Survival • Products • Trade • Income and wealth	• Market value
• Population abundance • Pollinator abundance	• Population abundance • Assemblage function	• Pollination—an intermediate ecosystem service	• Food • Nutrition • Survival • Products • Trade and income	• Market value • Stated preference
• Soil formation	• Ecosystem function	• Soil formation—an intermediate ecosystem service	• Food • Nutrition • Survival • Products • Trade and income	• Market value • Pollution control costs • Stated preference

Table 3. Examples of the relationships among conventional ecological assessment endpoints, GEAEs, generic ecosystem service assessment endpoints, ecological benefits and valuation (continued)

Conventional Ecological Assessment Endpoint	GEAE	Possible Generic Ecosystem Service Assessment Endpoint	Ecological Benefit	Potential Valuation Methods
• Water quality • Soil quality	• Ecosystem function	• Waste assimilation—an intermediate ecosystem service	• Waste treatment • Detoxification	• Pollution control costs • Stated preference
• Wilderness quality. Endangered species habitat area and quality	• Area or quality of ecosystem or special place	• Provision of aesthetic, scientific, recreational, educational cultural, medical, genetic, ornamental and spiritual resources—final ecosystem services	• Enjoyment of nature • Cultural fulfillment • Medical value	• Stated preference • Hedonic pricing • Benefits transfer

Section 5. Lessons Learned from Case Studies

5.1. Overview of Case Study Approach

This section summarizes a series of case studies that illustrate how ecosystem services have been or could be used to inform and communicate environmental management decisions. The complete case studies are provided in Appendix B. The decisions these case studies address range in scale from national to local and consider issues ranging from acidification and nutrient enrichment to invasive species, species extirpation, endangered species and remediation of hazardous waste sites. The decisions and regulatory authorities reflected include National Ambient Air Quality Standards (NAAQS) under the Clean Air Act (CAA), pesticide reregistration under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), benchmarks for stream invertebrates under the Clean Water Act (CWA), threatened and endangered species assessments under the Endangered Species Act (ESA),[25] and cleanup of Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The case studies are context specific and applicable only to the decisions being made and the regulatory or voluntary authorities guiding the decisions. To make the case studies comparable across different scales and types of the decisions, case study summaries are presented in this section using a similar format. This format includes (1) a description of the risk management decision the ecological risk assessment (ERA) was intended to inform, (2) a summary description of the ERA and how the risk information was used to inform the risk management decision, and (3) a discussion about how ecosystem service assessment endpoints might have added or did add value to the assessment beyond that provided by conventional assessment endpoints. Text boxes in the case study summaries illustrate conceptual relationships among conventional ecological assessment endpoints and ecosystem service assessment endpoints relative to case study stressors and ecosystem-derived benefits to humans.

5.2. Case Study Summaries

5.2.1. NO_xSO_x Secondary Standard Case Study

Policy/Decision Context

In 2006, the Office of Air Quality Planning and Standards (OAQPS) undertook a combined review of the secondary NAAQS for oxides of nitrogen (NO_x) and sulfur (SO_x) that included ecosystem effects. As part of the review, OAQPS developed a comprehensive risk and exposure assessment (REA) of effects of the two pollutants. Among the analyses included in the REA for NO_x and SO_x (USEPA 2009), OAQPS chose to address the ecosystem impacts in relation to their effects on ecosystem services.

Summary of the Ecological Risk Assessment and Decision

The NO_xSO_x REA identified two primary scenarios: (1) acidification caused by nitrogen and sulfur deposition, and (2) nutrient enrichment caused by nitrogen deposition. The terminology used in this paper to describe the ecosystem services evaluated in the REA differs somewhat from that used in the actual assessments to ensure consistency with the rest of this document. The following four case studies were chosen to evaluate these scenarios with selected ecosystem services:

- Aquatic acidification in Adirondack State Park and Shenandoah National Park, evaluating ecosystem services of recreational fishing, other recreational opportunities and aesthetics.

[25] 16 U.S.C. § 1531 et seq.

- Terrestrial acidification of red spruce and sugar maple habitat, evaluating ecosystem services of timber abundance, recreational opportunities and aesthetics.

- Aquatic enrichment of the Chesapeake Bay (Potomac River watershed) and Neuse River watershed, evaluating ecosystem services of fisheries abundance and recreational opportunities.

- Terrestrial enrichment of coastal sage scrub (CSS) and mixed conifer forest habitats in California (Los Angeles and Sierra Nevada Ranges), evaluating ecosystem services of recreational opportunities.

A literature review was conducted for each case study to assess the possibility of documenting the linkages between ambient air quality, nitrogen and sulfur deposition, quantifiable ecological effects of nitrogen and sulfur deposition and quantifiable effects on the ecosystem services associated with these ecological effects. For the policy option that reduced nitrogen and sulfur deposition to zero, marginal (incremental) changes in ecosystem service provision were quantified and monetized for recreational fishing in the Adirondacks, timber production in the red spruce/sugar maple range and recreational and aesthetic ecosystem services in the Chesapeake Bay. Significant information gaps were found within the chain of relationships associated with most other ecosystem services. Information gaps reflected inabilities to (1) predict marginal changes in ecosystem function given a level of pollutant, (2) predict the resulting change in ecosystem service provision given a change in ecosystem function, and (3) quantify values of changes in the level of ecosystem service provision either monetarily or using other value measures. For those ecosystem services that could not be addressed quantitatively, descriptions were given in the REA of the ecosystem services and their current levels of provision, considering that decrements in service provision resulting from nitrogen and sulfur deposition are embedded within the current level of provision (USEPA 2009). When possible, current (baseline) monetary values of ecological benefits at current levels of ecosystem service provision were included, along with descriptions of the potential adverse impacts of NO_x and SO_x on those ecosystem services. For example, travel costs of sightseeing trips were used to monetize partially the current value of the aesthetic ecosystem service of fall color provided by sugar maples, although projecting a change in the quality or quantity of sugar maple foliage that would result from a change in air deposition of nitrogen and sulfur was not possible.

The REA findings were considered in the Policy Assessment for the NO_xSO_x NAAQS review and the conclusions of the assessment were considered by the EPA Administrator in the review. The Administrator decided to retain the current standard for direct atmospheric effects to vegetation. With regard to deposition-related effects associated with NO_x and SO_x, the Administrator considered the appropriateness of a multipollutant standard and focused, in particular, on the approach for acidifying deposition developed in the Policy Assessment, for which she recognized a strong scientific basis. The Administrator concluded, however, setting a standard based on such an approach in light of the limitations of relevant data and the uncertainties associated with specifying the appropriate elements of such a standard were not appropriate (77 FR 20218). The decision was challenged in the U.S. Court of Appeals, District of Columbia Circuit, and EPA’s decision was upheld. As of the time of this writing, the next review of the NO_x and SO_x secondary standards is ongoing.

Lessons from the Case Study

The ecosystem service endpoints provided a frame of reference that enabled senior managers and the EPA Administrator to understand and discuss the effects of nitrogen and sulfur in the environment in terms that non-ecologists can readily appreciate. To the extent that the ecological benefits of different options could be quantified, the assessments characterized their magnitude (e.g., changes in the number of recreational fishing days) and significance in a meaningful way. The inclusion of a variety of ecological effects categories enabled managers to consider a broad range of possible ecological benefits for potential alternative standards. In addition, the ecosystem services construct could facilitate development of communication materials associated with the secondary NAAQS analyses that may be more understandable to the public than analyses focused on other endpoints.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
NO_x & SO_x	•fish abundance •fish production	•abundance of harvestable fish •amount of food	•recreation experiences •changes in food supply
NO_x & SO_x	•red spruce & sugar maple abundance	•amount of clean water •board feet of timber •gallons of maple syrup	•clean water for drinking •timber for construction •changes in food supply •recreation experiences
NO_x	•estuarine eutrophication	•biomass of harvestable fish •recreational opportunity •wildlife viewing	•changes in food supply •recreation experiences •aesthetic experiences
NO_x	•coastal sage scrub area •mixed coniferous forest area •T&E species habitat quality & area	•recreational opportunity •wildlife viewing	•recreation experiences •aesthetic experiences

5.2.2. Lampricide Case Study

Policy/Decision Context

Sea lamprey (*Petromyzon marinus)* is an invasive species in the Great Lakes that is parasitic to numerous commercial and sport fish populations. This case study focuses on the ecological risks from lampricide applications as determined by the ERAs drafted by the Office of Pesticide Programs for 3-trifluoromethyl-4-nitrophenol (TFM) and niclosamide and written in support of their reregistration eligibility decisions (REDs) (USEPA 1999). It concludes by describing how consideration of ecosystem services affected by the pesticide registrations could provide additional information on the impacts of lampricide use. In particular, the focus is on the impact of the presence of sea lampreys on the commercial and recreational fishing potential of the Great Lakes as mitigated by these pesticide registrations.

Summary of the Ecological Risk Assessment and Decision

Given estimates of exposure based on maximum treatment concentrations in aquatic ecosystems, risk quotients were derived by dividing the exposure values by ecotoxicity endpoints that are representative of impaired growth, survival and reproduction for the given species. The risk quotients then were compared to Office of Pesticide Program's levels of concern (LOCs) to determine potential risk to nontarget organisms and subsequent regulatory action.

Based on assessment results, no acute or chronic risks to mammals and birds (which are also surrogates for reptiles and terrestrial-phase amphibians) were expected as a result of use of either TFM or niclosamide. Acute LOCs for freshwater fish were exceeded, however, for the lampricidal use of TFM, niclosamide and the mixture of the two. Chronic toxicity data for freshwater fish for either TFM or niclosamide were not available. Acute risk LOCs also were exceeded for freshwater invertebrates for TFM, niclosamide and the mixture of the two. Furthermore, bottom-dwelling (benthic) invertebrates might be at greatest risk of death to TFM/niclosamide mixture treatments. Given that the persistence of TFM and niclosamide is uncertain, potential exposure of aquatic organisms to the compounds and subsequent effects could not be characterized, especially downstream of the treatment site. LOCs for risk to federally listed threatened and endangered species (hereafter referred to as listed species) were exceeded for freshwater fish and aquatic invertebrates for TFM and niclosamide. Listed and non-listed aquatic plant LOCs were exceeded for TFM but not for niclosamide.

Potential ways to mitigate risk include (1) varying the treatment rate based on pH; (2) applying lampricides to lower reaches of streams where sea lampreys might be localized, consequently permitting upper-reach native lamprey populations to repopulate lower reaches post treatment; (3) using a co-formulation of TFM and niclosamide (more efficacious on target species); and (4) treating affected streams every 3 to 5 years. Treatment efforts rely on stream flushing action to dissipate treatment chemicals at treatment sites and on dilution in the Great Lakes proper.

Lessons from the Case Study

The conventional measures of effect and the risk conclusions based on them can inform higher scale (e.g., population, ecosystem) assumptions of risk with an unspecified degree of uncertainty. The ecosystem services ascribed to the organisms directly or indirectly at risk aid in developing a larger scale risk picture that links an effect on a taxon to impacts on human populations. The ERAs performed for the lampricides—particularly the RED document (USEPA 1999) that was used for this case study—did not consider ecosystem service endpoints in assessing the potential ecological benefits and costs of lampricide use in Great Lakes ecosystems.

A formal benefits analysis was not conducted for TFM and niclosamide in the RED document (USEPA 1999). The U.S. Fish and Wildlife Service (USFWS) has provided an informal analysis that implies that sea lampreys have had a destructive impact on commercial and sport fish species in the Great Lakes and that reducing their numbers would provide benefits. In addition to other population control measures, the lampricides control an invasive species that, left unchecked, would seriously compromise commercially valuable fish populations and the fisheries that have developed around them. Therefore, if lampricides are not used, the invasive lamprey could destroy the ecosystem services of commercial and recreational fish as it has done in the past.

At the same time, lampricide use may lead to localized reductions in aquatic animal populations (nonparasitic lampreys and other nontarget organisms) from direct toxic effects on adults and developmental effects on larvae (e.g., abnormalities, susceptibility to predation, inability to forage) that lead to mortality. Furthermore, using these lampricides may affect some ecosystem services (e.g., some recreational fisheries) reliant on native fish and aquatic plant species on a spatially and temporally limited basis, but in the long-term would permit the reestablishment of these services. These negative effects of lampricides on ecosystem services would need to be considered in a comprehensive analysis.

In summary, not only is the sea lamprey itself capable of disturbing the aquatic food web of the freshwater lake system, but the pesticide used for its control could be ecologically disruptive, particularly at the treatment sites and areas directly downstream. Nevertheless, recovery from sea lamprey infestation of a commercial or sport fishery across all of the Great Lakes could take decades, whereas the direct disruptive effects of the lampricides on aquatic communities are relatively confined spatially and temporally.

Ultimately, this ERA might have benefited from additional evaluation of ecosystem services, such as biomass of harvestable fish and habitat quality. Having such data might have helped tie the use of lampricides to endpoints that people value, such as food production and recreational opportunities, and to nonuse services, such as the cultural and esthetic opportunities offered by the tributary and lake ecosystems.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
lampricides	•non-target species mortality	•biomass of harvestable fish •recreational opportunity	•changes in food supply •recreation experiences

5.2.3. Case Study of Stream Invertebrates Affected by Elevated Salinity

Policy/Decision Context

The leaching of overburden from surface coal mines in central Appalachia has been shown to increase salinity and adversely affect stream invertebrates. The Agency developed guidance for the regions and states on reviewing surface coal mining operations under the CWA (Stoner and Giles 2011). In support of that guidance, an assessment was performed to develop a benchmark value for conductivity (USEPA 2011).

Summary of the Ecological Risk Assessment and Decision

The assessment used the standard method for deriving ambient water quality criteria of calculating the fifth percentile of a species-sensitivity distribution. Field data, however, were used in place of laboratory data. The response was extirpation of macroinvertebrate genera. Hence, the assessment endpoint was protection of 95 percent of invertebrate genera from extirpation. The decision made based on the assessment was to set the benchmark for conductivity at 300 µS/cm for waters dominated by calcium and magnesium salts of bicarbonate and sulfate.

Because a benchmark that was consistent with established policies and procedures for water quality criteria was desired, substituting an ecosystem services endpoint was not necessary to set the level. Some stakeholders questioned, however, the importance of stream macroinvertebrates, particularly the sensitive mayflies. Responses to stakeholders described macroinvertebrates as important food for fish and for the retention of nutrients. The responses were included in the document that appears as Appendix B.3, which also includes other recreational and aesthetic services.

Lessons from the Case Study

Although the assessment endpoint was conventional, the importance of stream macroinvertebrates was unclear to decision makers and stakeholders. The descriptions of macroinvertebrate ecosystem services made the benchmark more understandable and acceptable. Hence, even when quantification of ecological benefits is not required or even appropriate, describing the ecosystem services associated with assessment endpoints can be critical to effective communication. The communication function of ecosystem services can make an important contribution to most ecological assessments.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
salinity	•macroinvertebrate occurrence	•recreational opportunity •wildlife viewing •aesthetic enjoyment	•recreation experiences

5.2.4. Threatened and Endangered Species Case Study

Policy/Decision Context

The California Red-Legged Frog (*Rana draytonii*) (CRLF) case study examines two ERAs that are representative of implementation of the ESA.[26] The ERAs were conducted to (1) identify critical habitat for the species and (2) examine the effects of pesticide use (Malathion[27]) upon the species' persistence.

As noted in the proposed rule for CRLF critical habitat, Section 4 of the ESA requires that the designation of critical habitat consider economic and other relevant impacts.[28] In addition, FIFRA requires that commercially available pesticides also undergo ERA to determine if they will contribute to the stress on species listed under the ESA. Therefore, the use of Malathion was assessed for its effect on the CRLF.

Summary of the Ecological Risk Assessment and Decision

Assessment endpoints for the CRLF habitat assessment were the primary constituent elements for the species. The endpoints for the primary constituent elements included space for individual and population growth and for normal behavior; food, water, air, light, minerals or other nutritional or physiological requirements; cover or shelter; sites for breeding, reproduction and rearing (or development) of offspring; and habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of a species.[29]

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[26] Endangered Species Act of 1973, 16 U.S.C. § 1536(a)(1).

[27] Malathion is an organophosphate insecticide that has been registered for use in the United States since 1956. It is used in agriculture, residential gardens, public recreation areas and public health pest control programs. When applied in accordance with the rate of application and safety precautions specified on the label, Malathion can be used to kill mosquitoes without posing unreasonable risks to human health or the environment. See EPA's Malathion website, http://www2.epa.gov/mosquitocontrol/malathion.

[28] Proposed Rules, 70 *Fed. Reg.* 212 (Nov. 3, 2005), 66906.

[29] Proposed Rules, 70 *Fed. Reg.* 212 (Nov. 3, 2005), 66911.

In the determination of CRLF critical habitat, the USFWS's consideration of economic impacts effectively excluded land from designation based on it's markedly "higher value" for other uses. Several comments on the proposed rule stated that the USFWS's economic analysis "failed to provide a balanced assessment of economic benefits (such as water filtering and general habitat protection) and costs in relation to the revised proposed critical habitat designation." The USFWS responded that the "[US]FWS's approach for estimating economic impacts includes both efficiency and distributional effects" and "[w]here data are available, the economic analyses do attempt to measure net economic impact."[30] The net economic impact to which the USFWS appeared to be referring was described in terms of changes in opportunity costs (i.e., the value of goods and services foregone) to comply with the critical area designation. The USFWS did not consider "broader social values" as described by the benefit categories outlined by commenters as part of these "more conventionally defined economic impacts" and did not include them in economic assessments. Further, the USFWS said that, as a practical matter, quantification of these types of values is challenging.

Similarly, the Malathion ERA used primary constituent elements as assessment endpoints. Economic considerations were incorporated into the management decision but only to the extent that the value of the pesticide in its use was considered. Ecological benefits associated with preserving habitat or ecosystem services derived from that habitat protection were not included in the ERA or in the management decision.

Lessons from the Case Study

The USFWS did not consider the full spectrum of ecological benefits of habitat protection, although such valuation could be legally considered within a benefit-cost analysis. The ESA is silent about how costs and benefits are to be weighed and determined. The incorporation of ecosystem service valuation in the primary constituent elements of any land assessed and evaluated for exclusion from critical habitat designation might result in a net increase of the land's value for protection when balanced against its value for other purposes, altering the final management determination. This same logic could be extended to any ERA conducted to evaluate the effect of a pesticide on an endangered species. Whether ERAs intended to inform decisions involving listed species would be enhanced by ecosystem service concepts remains unclear because the ESA and associated regulations clearly define the information that is needed for decisions.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
pesticides	•critical habitat quality	•recreational opportunity	•recreation experiences

[30] Rules and Regulations: Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the California Red-Legged Frog, and Special Rule Exemption Associated with Final Listing for Existing Routine Ranching Activities, 71 *Fed. Reg*. 71 (Apr. 13, 2006), 19258. http://www.epa.gov/fedrgstr/EPA-SPECIES/2006/April/Day-13/e3344.htm.

5.2.5. Hazardous Waste Site Case Study

Policy/Decision Context

This case study involves a Superfund hazardous waste site located along the Raritan River in central New Jersey. Screening-level and baseline ERAs (SLERAs and BERAs) were performed by EPA to assess site risk and inform remedial decisions in accordance with CERCLA.

Summary of the Ecological Risk Assessment and Decision

The endpoints considered in the SLERA included survival, growth and reproduction of representative bird and mammal species (food chain exposure), amphibian and crustacean species (surface water exposure) and the benthic community (sediment and water exposure). A baseline ecological risk assessment (BERA) then was performed based on the results of the SLERA's finding of potential risks to ecological receptors from three primary contaminants of concern: polychlorinated biphenyls (PCBs), arsenic and mercury.

Abundance and production endpoints were considered in the BERA: aquatic macroinvertebrate and terrestrial invertebrate communities (sediment exposure), estuarine fish populations and community structure (water and tissue exposure) and wildlife abundance (food chain exposure). Potential risks in specific areas of the site identified in the BERA included impacts from contaminated river sediment and marsh areas on the benthic community, aquatic and terrestrial invertebrates and aquatic mammals such as muskrats. Fish populations were not considered to be at risk.

In selecting a remedial alternative, EPA based its decision on consideration of the site investigation and risk assessment, CERCLA requirements, analysis of response measures and public comments. The remedial action determined by EPA was full excavation and restoration of the marsh and deep dredge and cover for the river sediments.

Ecosystem services were not explicitly considered in the ERA for this site. In making the remediation decisions, however, EPA indirectly considered the impact on human uses when assessing estuarine fishes. Based on PCB levels in selected fish species and blue crabs in the Raritan River near the site, contaminant concentrations in locally collected crabs and fish were compared to State of New Jersey fishing advisories. Elevated concentrations, however, were not found.

Lessons from the Case Study

Local community comments on EPA's proposed remedial measures generally were concerned with the sufficiency of protective measures. One comment reflected concern that the costs of remediation were high in contrast to a perceived minimal risk to humans.

A remedial decision that offers little or no improvement to human health does not exclude other benefits to the ecosystem or to humans. Explicitly considering and communicating ecosystem services in the ERA related to the selection of remedial actions likely would have changed the assessment of risks and public acceptance of the remedial decisions. The remedial action included onsite restoration of six acres of wetlands that should restore the ecosystem services of the marsh, including changing from a lower value *Phragmites* marsh to a more diverse, higher functioning system. EPA also could have communicated the benefit of restoring services provided by clean river sediments, which might have reduced public concerns. The benefits of site remediation include restoration of ecosystem services associated with recreational uses, water purification and flood stage reduction. Issues regarding cleanup costs might be reduced if the public could understand more fully how they will benefit in the long term through positive changes in ecosystem services from the selected remedial decisions.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
chemicals	•aquatic invertebrate survival, growth, and reproduction	•biomass of harvestable fish •recreational opportunity	•changes in food supply •recreation experiences

5.3. Observations from Case Studies

The case studies summarized here and described fully in Appendix B serve as examples for how ecosystem service assessment endpoints could complement conventional assessment endpoints in Agency ERAs. For the most part, the case studies suggest how decisions could be informed or communicated better by incorporating ecosystem service assessment endpoints more explicitly in the ERAs supporting a broad range of decisions made by the Agency. As described in Section 2.3, including ecosystem service assessment endpoints in such assessments is consistent with existing law and regulations. Whether ERAs intended to inform decisions involving listed species would be enhanced by ecosystem service concepts remains unclear because the ESA and associated regulations clearly define the information that is needed for decisions.

Only one case study ERA, the NO_xSO_x secondary NAAQS, included ecosystem service assessment endpoints in the original assessment. The endpoints were included largely because ecosystem service assessment endpoints were determined to be consistent with the language of the CAA. Including them provided additional meaningful input to considerations of various options regarding the secondary standard and facilitated communication to EPA's Administrator and the public about the ramifications associated with those options. The lampricide case study highlighted the positive and negative ecological consequences of lampricide use, suggesting that ecosystem service assessment endpoints could have helped balance those consequences in the reregistration decision by considering the ecological/socio-economic system more holistically. The stream invertebrate case study illustrated how descriptions of ecosystem services associated with macroinvertebrates, provided as an addendum to the ERA, helped in communicating the salinity benchmark decision, rendering it more understandable and acceptable. The hazardous waste site case study suggested that the public's perceptions and acceptance of site cleanup costs might have been enhanced had ecosystem service assessment endpoints been included in the ERA and the long-term ecological benefits of ecosystem services improvements been communicated. Even for Agency actions that potentially affect listed species, which have assessment requirements delineated clearly by the ESA and associated regulations, ecosystem service assessment endpoints could provide information about the ecological benefits of various decision alternatives that might alter management determinations, as suggested by the listed species case study.

Some of the case studies highlighted the linkages that can be made between conventional assessment endpoints and the endpoints linked more closely to ecological benefits. Although the more obvious ones tied production of fishery species to recreational and food availability benefits, nonuse benefits also were suggested. The case study illustration text boxes provided in this section convey some of the potential relationships between conventional assessment endpoints and ecosystem service assessment endpoints.

Overall, the case studies suggested that including ecosystem services as endpoints in the assessments would have enabled evaluation of a more comprehensive set of information and, potentially, clearer communication to stakeholders of the rationale behind decisions made. These advantages should contribute positively to the risk assessment and management process.

Section 6. Next Steps

6.1. Technical Reference Development

The integration of ecosystem service assessment endpoints into the technical reference guide on generic ecosystem assessment endpoints (GEAE) is recommended based on the technical information provided here. Ecosystem service endpoints are useful in the ecological risk assessment (ERA) process. Their use can improve the extent to which the impacts and issues associated with ecosystem function are considered in the assessment and the decision-making process. Incorporating ecosystem services into the decision-making process enables decision makers to better balance considerations of environmental, ecological and social elements and move toward making better-informed, sustainable decisions. The development of generic ecosystem service assessment endpoints will facilitate their consideration and use during problem formulation. Generic ecosystem service assessment endpoints that are responsive to the decision should be tailored to the environmental and decision contexts of the assessment. By including these endpoints, environmental management decisions are likely to be made more holistically, thereby minimizing the potential for unintended consequences that might result from those decisions.

The ecosystem services construct provides an opportunity to integrate quantitatively or qualitatively human well-being in ecological decision making. As shown by the case study examples, the decision context is critical to determining which ecosystem services would be useful to the decision-making process. In some cases, the qualitative outputs of the risk assessment, such as a list of goods and services that are jeopardized by the predicted ecological effects, is sufficient to inform a decision (e.g., the stream invertebrate case study). In other cases, monetization of the ecological benefits that are associated with the ecosystem services affected and the tradeoffs between alternative decision options can be helpful. In such cases, ecosystem service assessment endpoints should be selected that are conducive to monetization. This process may require involving economists in the endpoint selection process. Worth noting, however, is that some attributes of organisms, populations and communities (e.g., species richness) are valued despite their not being obvious final ecosystem services (NAS 2004). Therefore, conventional ecological assessment endpoints still should be used in ERAs.

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. Challenges to their routine inclusion in risk assessments remain, however, as demonstrated in several of the case studies. Information gaps in the chain of relationships between effects on ecological endpoints, such as the abundance of a fish population, and effects on human welfare might be unknown, or might be only modeled. Thus, the need to advance the knowledge base to enable widespread adoption of this method is ongoing.

6.2. Ecosystem Service Science Needs

The *Millennium Ecosystem Assessment* (MEA 2005) and notable predecessor efforts (e.g., Costanza et al. 1997; Daily 1997) brought international attention to the contributions made by ecosystems to human well-being. The science underlying environmental policy based on this awareness continues to evolve rapidly. Adopting a standardized lexicon of ecosystem services terms and definitions is important to facilitate communication and understanding (Munns et al. 2015). Also key will be expanding the list of GEAEs to include explicitly those that incorporate ecosystem services. The communication of ecosystem services concepts and research results through training opportunities for ecological risk assessors and risk managers is recommended to enable them to understand more fully how ecosystem services can be used in the ERA process.

Continued research is needed to refine and advance the development of the concepts, information and tools required to incorporate ecosystem service assessment endpoints in ERA routinely. Research needs associated with adopting the use of ecosystem services as assessment endpoints include:

- Developing approaches to measure the current state of ecosystem service delivery.
- Developing models and tools that quantify changes in final ecosystem services as functions of environmental stressor exposure. Decisions may be based on the incremental changes in effects, and quantifying these changes can have a high impact on the decision. Examples of such tools identified in the case studies include those that quantify, visualize and evaluate anticipated impacts of hazardous waste site remediation decisions, pesticide reregistration decisions and secondary National Ambient Air Quality Standard decisions on ecosystem services.
- Developing a more comprehensive understanding of the relationships between ecosystem service changes and human health and well-being (see Sandifer et al. 2015).
- Developing approaches that characterize ecological production functions and catalogs of generic ecological production functions.
- Developing tools and models that relate ecosystem services to conventional assessment endpoints (e.g., the relationship between a toxicity endpoint quantified at the organismal level and a suite of ecosystem services).
- Developing and evaluating approaches to participatory stakeholder engagement to facilitate identification of valued ecosystem service assessment endpoints during assessment endpoint selection.

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Appendix A. Valuation Methods

Ecosystem services contribute to the welfare of humans and society. People benefit when decisions affecting the environment enhance ecosystem services. Yet in many situations, multiple options or alternatives might exist for the environmental decision being made. Selection of the best among these alternatives—the ones that will optimize delivery of ecosystem services and the ecological benefits they provide to society—is supported by an understanding of the values humans ascribe to ecosystem services.

The Agency's *Ecological Benefits Assessment Strategic Plan* (USEPA 2006) defines valuation as the act or process of estimating the worth, merit or desirability of a wide variety of environmental conditions in common units that can be aggregated and compared. This definition has two key implications. First, value is "in the eyes of the beholder" and should be defined from the perspective of that beholder. Although not without potential controversy, the position taken in the ecosystem services concept is anthropocentric: the "beholders" are humans and society. Thus, society provides the frame of reference for determining the value of ecosystem services and changes thereof with environmental decisions made with these values in mind. The second implication stems from the notion of "common units." One such unit that generally is accepted by society and our governance is money. When values are quantified in monetary terms (a process called monetization or economic valuation), the benefits of competing alternatives in decision making can be compared directly with the costs of implementing those alternatives, a process formalized in benefit-cost analysis. This is not to say that people only value money; indeed, any number of philosophical, spiritual, moral and other beliefs and attitudes contribute to the values that people place on ecosystems and the decisions affecting them. Rather, money is a convenient common unit with which to quantify, aggregate and compare these values. Monetization, however, sometimes is not feasible, practical or desirable. In such instances, other approaches can be used to value changes in ecosystem services in nonmonetary terms that are useful to environmental decision makers. Heberling and Bruins (2005), Adamowicz et al. (2007), SAB (2009) and the U.S. Environmental Protection Agency (EPA or the Agency) (2010) provide accessible descriptions of valuation concepts and methods.

Table A-1 describes the different kinds of benefits that people and society enjoy from ecosystem services (USEPA 2006) and provides a convenient framework for describing economic valuation methods. The value of ecosystem goods and services that are sold and bought in markets, such as food and fiber, can be estimated as a function of the money exchanging hands in these markets. "Revealed preference" methods rely on observations of prices established by markets for ecosystem goods and services used to produce other market goods. Revealed preference methods also can be used to quantify the value of certain environmental services that are not traded in markets (nonmarket benefits), such as those that affect market goods directly or indirectly (e.g., for environmental amenities that affect housing prices), or the aesthetic amenities provided by natural places (inferred from the money people have spent to visit those places).

In the absence of information describing values as revealed by people's past and current behaviors, stated preference methods can be employed to evaluate the economic tradeoffs that people are willing to make to protect ecosystems. These methods depend on people's responses to questions asking how much they would pay to protect or enhance ecosystems and their services ("willingness to pay" or WTP), or to be compensated if such actions were to not take place ("willingness to accept"). Information typically is collected using survey instruments that offer choices among various environmental alternatives and the costs associated with each. Stated preference methods are useful for eliciting values of the direct-use, indirect-use and nonuse benefits described in Table A-1.

Table A-1. Types of ecological benefits categorized by benefit type

Benefit Category		Explanation	Examples
Market		Generally relate to primary products that can be bought or sold as factors of production or final consumption products	• Food and water sources: commercial fish and livestock, game fish and wildlife, drinking water • Building materials: timber • Fuel: methane, wood • Clothing: leather, fibers • Medicines: nature-derived pharmaceuticals
Non-market	Direct-use	Directly sought and used or enjoyed by society; includes both consumptive uses and nonconsumptive uses	• Consumptive recreational: fishing, hunting • Nonconsumptive recreational: boating, swimming, camping, sunbathing, walking, climbing, bird watching, sightseeing, enjoyment of visual amenities
	Indirect-use	Indirectly benefit society; may be valued because they support offsite ecological resources or maintain the biological and/or biochemical processes required for life support	• Maintenance of biodiversity • Maintenance and protection of habitat • Pollination of crops and natural vegetation • Dispersal of seeds • Protection of property from floods and storms • Water supply (e.g., groundwater recharge) • Water purification • Pest and pathogen control • Energy and nutrient exchange
	Non-use	Benefit does not depend on current use or indirect benefits; individuals might value the resource without ever intending to use it or might have a sense of environmental stewardship; includes bequest value, existence value, and cultural/historic value	• Perpetuation of an endangered species • Wilderness areas set-aside for future generations

Source: USEPA (2006).

The neoclassical environmental economic approaches just described are based on a unifying conceptual framework for considering social welfare that directly supports economic analysis of tradeoffs. A variety of other approaches, summarized by EPA (2010) as sociocultural assessment methods and the SAB (2009) as social-psychological valuation methods, relies on the judgments of individuals and groups to support environmental decision making. Included are various methods (e.g., multicriteria decision making, Delphi methods, referenda) that seek to elicit the opinions and expert judgments that can help uncover societal preferences and rank the acceptability of alternative options under consideration. Although they do not lend themselves easily (if at all) to monetization of values, such approaches provide information about the values that people place on ecosystem services.

Neoclassical environmental economic approaches (and to some extent sociocultural assessment methods) consider social welfare to be the objective and assume ecosystems to be part of the economy. An alternative paradigm and set of valuation approaches have been proposed by ecological economists who consider the economy to be one component of a broader environmental system (e.g., Daly 1992, Campbell 2001). This paradigm shifts the focus from humans to ecosystems and defines value in terms of biophysical stocks and flows instead of directly in terms of human welfare. Various methods, including those based on theories and models of energy flow, can be used for deducing value from this vantage and comparing the spatial ecological footprints required to support individuals and communities (see Heberling and Bruins [2005] for a succinct summary of these approaches). In spite of the many attractions it offers to the issue of valuation, the field of ecological economics has yet to converge on a central set of theories and core framework of analysis as needed by environmental policy and decision making. Until these are developed, the value of ecological economic approaches to environmental decision making likely will be limited.

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Appendix B. Case Studies

Case studies can illustrate how the ecosystem services concept can be used to inform and communicate environmental management decisions. The decisions addressed by these case studies range in scale from national to local and consider issues ranging from acidification and nutrient enrichment to invasive species, species extirpation, endangered species and remediation of hazardous waste sites. The regulatory authorities range from National Ambient Air Quality Standards (NAAQS) under the Clean Air Act (CAA)[31] to pesticide reregistration, benchmarks for stream invertebrates under the Clean Water Act (CWA);[32] threatened and endangered species assessments under the Endangered Species Act (ESA);[33] and cleanup of Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)[34].

By their nature, the case studies are applicable only to the decisions being made and the regulatory or voluntary authorities guiding the decisions. In an attempt to make the case studies comparable across the scales and nature of the decisions being informed, they are presented in this appendix using a similar format. This format includes a description of the risk management decision that the ecological risk assessment (ERA) was intended to inform, including contextual information as appropriate; a summary description of the ERA, including the assessment and measures of effect involved; and how the risk information was used to inform the risk management decision. If the ERA already included ecosystem service assessment endpoints explicitly, a discussion on how the information added value compared with conventional assessment endpoints is included. If the ERA included only conventional assessment endpoints, however, a discussion is presented on how the ERA might have been made more informative by including ecosystem service assessment endpoints. Unnumbered text boxes in the case studies illustrate conceptual relationships among conventional ecological assessment endpoints and ecosystem service assessment endpoints relative to case study stressors and ecosystem-derived benefits to humans.

B.1. Oxides of Nitrogen and Sulfur Secondary Standard Case Study

B.1.1. Policy/Decision Context

The risk and exposure assessment (REA) for oxides of nitrogen and sulfur (NO_x and SO_x) was conducted to inform the U.S. Environmental Protection Agency (EPA or the Agency) Administrator's decision on setting new secondary standards for NAAQS for these pollutants. NAAQS are established for pollutants that reasonably may be anticipated to endanger public health or welfare and the presence of which in the ambient air results from numerous or diverse mobile or stationary sources. The primary NAAQS protect public health, and the secondary NAAQS protect public welfare, one constituent of which includes ecological condition. NAAQS are based on air quality criteria that reflect the latest scientific knowledge, as reviewed in the Integrated Science Assessment (USEPA 2008). The REA (USEPA 2009) develops analyses of the risk or exposures associated with the presence of the pollutant in ambient air. When conducted, these analyses are among the considerations that inform the EPA Administrator's decision on the whether to retain or revise the NAAQS, and if to revise, what revisions may be appropriate.

[31] 42 U.S.C. § 7401 et seq.
[32] 33 U.S.C. § 1251 et seq.
[33] 16 U.S.C. § 1531 et seq.
[34] 42 U.S.C. § 9601 et seq.

The EPA Office of Air Quality Planning and Standards recently conducted a joint review of the existing secondary (welfare-based) NAAQS for NO_x[35] and SO_x. Considering currently available information on known or anticipated potential adverse effects to public welfare associated with specified pollutants in ambient air is an important component of any secondary NAAQS review. According to Section 302(h) of the CAA, welfare effects include:

> "…effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants."

Although the text above lists several welfare effects, these effects are not effects on public welfare in and of themselves. It is important to distinguish between an effect on welfare in general and an effect on public welfare, which, as defined, explicitly indicates an effect on humans.

Thus, considering the effects of NO_x and SO_x on ecosystem services is worthwhile because ecosystem services can be related directly to aspects of public welfare to inform discussions of societal adverse impacts. Observed or predicted changes in ecosystem services caused by changes in pollutant concentrations may be used to characterize a known or anticipated adverse effects on public welfare; such effects could be, expressed as the changes in direct benefits or monetary value of costs associated with ecosystem services under current levels of these pollutants in the atmosphere.

B.1.2. Summary of the Ecological Risk Assessment

In conducting this periodic review of the NO_x and SO_x secondary NAAQS, EPA's Office of Air and Radiation decided to assess jointly the scientific information, associated risks and standards relevant to protecting the public welfare from adverse effects associated with NO_x and SO_x. A joint secondary review of these pollutants was conducted because NO_x, SO_x and their associated transformation products are linked from an atmospheric chemistry perspective. The review, informed by conclusions presented in the Integrated Science Assessment, identified acidification caused by nitrogen and sulfur deposition, as well as nutrient enrichment caused by nitrogen deposition, as primary focus areas. To that purpose, four relevant case studies were chosen:

- Aquatic acidification—the Adirondack State Park and the Shenandoah National Park.
- Terrestrial acidification—red spruce and sugar maple habitat.
- Aquatic enrichment—the Chesapeake Bay (Potomac River watershed) and Neuse River watershed.
- Terrestrial enrichment—coastal sage scrub (CSS) and mixed conifer forest habitats in California (Los Angeles and Sierra Nevada Ranges).

For each case study, a literature review was conducted to assess the possibility of following the linkages from ambient air quality to nitrogen and sulfur deposition, quantifiable ecological effects of nitrogen and sulfur deposition, and finally, quantifiable effects on the ecosystem services associated with the

[35] The term NO_x refers to all forms of oxidized nitrogen compounds, as defined by Section 108(c) of the CAA, which states that "Such criteria [for oxides of nitrogen] shall include a discussion of nitric and nitrous acids, nitrites, nitrates, nitrosamines, and other carcinogenic and potentially carcinogenic derivatives of oxides of nitrogen." The term used by the scientific community to represent the complete set of oxidized nitrogen compounds, including those listed in CAA Section 108(c), is total oxidized nitrogen (NO_y).

ecological effect. For most services, this chain of relationships had significant information gaps. In this risk assessment, the analysis proceeded as far as possible along this analytical pathway to quantify current levels of provision of the selected services. The Policy Assessment Document (USEPA 2011c) is the next step in the policy process that synthesizes the information in the Integrated Science Assessment and REA (USEPA 2008, 2009), and concludes whether the consideration of retaining or revising the current standards is appropriate. If the conclusion is that considering revision is appropriate, the Policy Assessment concludes what revisions are appropriate for the EPA Administrator to consider. In the Policy Assessment, when data and methods were available, attempts were made to quantify the level of harm that had accrued to services since 1860 (a proxy for pristine ecosystems).

Aquatic Acidification

Acidification effects have been noted since the 17th century, when the industrial revolution began causing increased emissions of nitrogen and sulfur. A wealth of information is available on acidification effects on fish; in particular, the lakes of the Adirondacks State Park have been a focus of considerable research. Because the best data and the clearest links between atmospheric deposition, ecological effect and the associated services were available, this case study became the focus of the review and subsequent policy assessment.

Acidification primarily affects the ecosystem services that are derived from the fish and other aquatic life found in these surface waters (USEPA 2009, Section 5.2.1.3). In the northeastern United States, the surface waters affected by acidification are not a major source of commercially raised or caught fish; however, they are a source of food for some recreational and subsistence fishers and for other consumers. Although data and models are available for examining the effects on recreational fishing, relatively little data are available for measuring the effects on subsistence and other consumers. For example, although evidence exists that certain population subgroups in the northeastern United States, such as the Hmong and Chippewa ethnic groups, have particularly high rates of self-caught fish consumption (Hutchison and Kraft 1994; Peterson et al. 1994), if and how their consumption patterns are affected by the reductions in available fish populations caused by surface water acidification is unknown.

Inland surface waters support several cultural services, such as recreational fishing, and aesthetic and educational services; however, Banzhaf et al. (2006) has shown that nonuse services, which include existence (protection and preservation with no expectation of direct use) and bequest values, arguably are a significant source of benefits from reduced acidification. The areas of the country containing the most sensitive lakes and streams are New England, the Adirondack Mountains, part of the Adirondack Forest Preserve that has been set aside to be kept “forever wild,” the Appalachian Mountains (northern Appalachian Plateau and Ridge/Blue Ridge region) and the Upper Midwest. The characterization of “sensitivity” depends on the bedrock geology, surface water flow, soil depth and weathering rates that contribute to high potential for acidification.

As part of the REA (USEPA 2009), this analysis was able to characterize quantitatively the current level of provision for only one of the many services mentioned above. The “willingness to pay” (WTP) for recreational fishing in the Adirondacks was quantified and monetized using complementary approaches based on a water quality model linked to a random utility recreational fishing model (travel cost), and by contrast, WTP estimates from a contingent valuation survey of New York residents. Unfortunately, this quantifying recreational fishing impacts on a regional or national scale was not possible with this analysis. For example, data from the 2006 National Survey of Fishing, Hunting, and Wildlife Associated Recreation (USDOI and USDOC 2007) indicate that more than 9 percent of adults in the northeastern United States participate annually in freshwater fishing with 140 million freshwater fishing days. Based on studies conducted in the northeastern United States, Kaval and Loomis (2003) estimated average consumer surplus values per day of $35 for recreational fishing (in 2007 dollars). Therefore, the implied total annual value of freshwater fishing in the northeastern United States was $5 billion in 2006. Although these numbers indicate the magnitude of the current provision of service, it should be recognized that embedded in these numbers is a degree of harm to recreational fishing services that has resulted from acidification, which has occurred over time and cannot be quantified.

The ecosystem services most likely to be affected by nitrogen and sulfur deposition, as well as evidence regarding the current magnitude and values of recreational fishing services, are described above. The degree to which these services are impaired by existing NO_x and SO_x levels has not been quantified. To address this limitation, the REA (USEPA 2009, Appendix 8) provides insights into the magnitude of ecosystem service impairments. The analysis of ecosystem service impairments caused by aquatic acidification builds on the case study analysis of lakes in the New York Adirondacks. In this study, estimates of changes in recreational fishing services are determined, as well as changes more broadly in "cultural" ecosystem services (including recreational, aesthetic and nonuse services).

MAGIC (Model of Acidification of Groundwater in Catchments) (USEPA 2009, Appendix 8, Section 2.2) was applied to 44 lakes to predict what levels of acid neutralizing capacity (ANC) would be found under "business-as-usual" conditions (i.e., allowing for some decline in deposition resulting from existing regulations) and pre-emission (i.e., background) conditions. These model runs assumed a 2010 "zero-out" emissions scenario (in which all nitrogen and sulfur deposition is eliminated) with a projected lag time between the elimination of emissions to observed improvement in ANC of 10 years; therefore, ecological benefits results were calculated for 2020. These predictions then were extrapolated to the full universe of Adirondack lakes.

To estimate the recreational fishing impacts of aquatic acidification in these lakes, an existing model of recreational fishing demand and site choice was applied. This model predicts how recreational fishing patterns in the Adirondacks would differ and how much higher the average annual value of recreational fishing services would be for New York residents if lake ANC levels corresponded to background (rather than business-as-usual) conditions.

Current annual impairments in value are most likely of similar magnitude to those modeled because, although current NO_x and SO_x levels are somewhat higher than those expected in 2020 (under business as usual: given expected emissions controls associated with Title IV regulations but no additional nitrogen or sulfur controls), the affected New York population is somewhat smaller (based on U.S. Census Bureau projections).

To estimate impacts on a broader category of cultural (and some provisioning) ecosystem services, results from the Banzhaf et al. (2006) valuation survey of New York residents were adapted and applied to this context. The survey used a contingent valuation approach to estimate the average annual household WTP for future reductions (20 percent and 45 percent) in the percentage of Adirondack lakes impaired by acidification. The focus of the survey was on impacts on aquatic resources. Pretesting of the survey indicated that respondents nonetheless tended to assume that ecological benefits would occur in the condition of birds and forests and in recreational fishing. The survey that measured the benefits of 20 percent of the lakes improving indicated that terrestrial benefits were minor; therefore, econometric controls were used to adjust the WTP estimate for those that suspected that terrestrial improvements were greater than described in the survey. The survey that measured the benefits of improving 45 percent of the total number of lakes also indicated that the benefits to forests and birds were significant.

The WTP estimates from the two versions of the survey were then (1) scaled to reflect predicted changes between business-as-usual and background conditions in 2020 (MAGIC lake modeling results indicate that impaired lakes would decrease from 22 percent to 31 percent using background conditions with ANC increasing from 20 to 50 μeq/L) and (2) aggregated across New York households. The scaling entails converting the average household WTP for the improvements described in the Adirondacks surveys to an average household WTP per percentage point of the total population of lakes improved.[36] Estimates are provided at ANC values of 20, 50 and 100 µeq/L to reflect the range of ANC discussed throughout the REA (USEPA 2009) and for consistency with the Random Utility Model analysis.

Although no direct matches exist, the closest correspondence is between the zero-out scenario assuming a 50-µeq/L threshold and the Banzhaf et al. (2006) scope survey. Using the range of WTP Adirondacks values from the Banzhaf et al. (2006) scope survey and the projected number of New York households in 2010, the aggregate annual benefits of the zero-out scenario are estimated to range from $291 to $829 million. With the 20-µeq/L threshold, the aggregate benefits are estimated to range from $411 to $916 million per year. With the 100-µeq/L threshold, the aggregate benefits are estimated to range from $492 million to $1.1 billion per year.

These results suggest that the value of avoiding current impairments to ecosystem services from Adirondack lakes is even higher than the estimate because the estimates assume a lag of 10 years in which no benefits accrue and the percentage of impaired lakes is slightly higher today than expected in 2020 under business-as-usual. These results imply significant value to the public in addition to that derived from recreational fishing services. It should be noted that the results are applicable only to improvements in the Adirondacks valued by residents of New York. Values to non-New York residents are not considered in this study, indicating that this estimate of benefits is likely very conservative. If similar benefits exist in other acid-impacted areas, benefits for the nation as a whole could be substantial.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
NO_x & SO_x	•fish abundance •fish production	•abundance of harvestable fish •amount of food	•recreation experiences •changes in food supply

<u>Terrestrial Acidification</u>

In the REA (USEPA 2009), the effects of acidifying deposition on terrestrial ecosystems, especially forests, were discussed. These include the observed decline and dieback in red spruce and sugar maple. These species are particularly sensitive to acidifying deposition and have ranges that overlap the areas of the United States where some of the highest levels of acidifying deposition occur.

Numerous services are expected to be affected, but the data and methods to describe those losses adequately do not yet exist. These services include effects on forest health, water quality and habitat, including decline in habitat for threatened and endangered species (hereafter referred to as "listed" species), decline in forest aesthetics, decline in forest productivity, increases in forest soil erosion, and decreases in water retention (Krieger 2001; USEPA 2009). Forests in the northeastern United States provide several important and valuable provisioning services that are reflected in the production and sales of tree products. Sugar maples are a particularly important commercial hardwood tree species in the United States, producing timber and maple syrup that provide hundreds of millions of dollars in economic

[36] Scaling is required because neither survey administered by Banzhaf et al. (2006) describe improvements that correspond exactly to the improvement scenario modeled here.

value annually (NASS 2008). Red spruce also is used in a variety of wood products and provides up to $100 million in economic value annually (NASS 2008).

Forests in the northeastern United States also are an important source of cultural ecosystem services, including nonuse (existence value for listed species), recreational and aesthetic services (USEPA 2009). Although no data are available to link acidification damages directly to economic values of lost recreational services in forests, these resources are valuable to the public. For example, the most recent data from the National Survey on Recreation and the Environment (Cordell et al. 2013) indicate that from 2004 to 2007, 31 percent of the U.S. adult (16 years of age and older) population visited a wilderness or primitive area during the previous year, and 32 percent engaged in day hiking (Cordell et al. 2013). A recent study suggests that the total annual value of off-road driving recreation was more than $9 billion, and the total values of hunting and wildlife viewing were more than $4 billion each in the northeastern United States in 2006 (Kaval and Loomis 2003). In addition, fall color viewing is a recreational activity that directly depends on forest conditions. Forests in the northeastern United States also support and provide a wide variety of valuable regulating services, including soil stabilization and erosion control, water regulation and climate regulation (Krieger 2001). Forest vegetation plays an important role in maintaining soils to reduce erosion, runoff and sedimentation that can adversely affect surface waters. In addition to protecting water quality in this way, forests also help store and regulate the quantities and temporal discharge patterns of water in watersheds. Forests also play an important role in carbon sequestration at regional and global scales. The total value of these ecosystem services could not be quantified in this analysis.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
NO_x & SO_x	•red spruce & sugar maple abundance	•amount of clean water •board feet of timber •gallons of maple syrup	•clean water for drinking •timber for construction •changes in food supply •recreation experiences

Aquatic Nutrient Enrichment

Estuaries in the eastern United States are important for fish and shellfish production. The estuaries are capable of supporting large stocks of resident commercial species, and they serve as the breeding grounds and interim habitat for several migratory species (USEPA 2009). To provide an indication of the magnitude of provisioning services associated with coastal fisheries, the average value of total catch was $1.5 billion per year from 2005 to 2007 in 15 East Coast states. What percentage of this value is directly attributable to or depends on the estuaries in these states, however, is unknown.

Estuaries in the eastern United States also provide an important and substantial variety of cultural ecosystem services, including water-based recreational and aesthetic services. Estuaries and marshes have the potential to support a wide range of regulating services, including climate, biological and water regulation; pollution detoxification; erosion prevention; and protection against natural hazards (MEA 2005). The relative lack of empirical models and valuation studies imposes obstacles to the estimation of ecosystem services affected by nitrogen deposition. Although atmospheric deposition contributes to eutrophication, there is uncertainty in separating the effects of atmospheric nitrogen from nitrogen reaching the estuaries from several other sources. The REA analysis (USEPA 2009) estimates the change in several ecosystem services, including recreational fishing, boating, beach use, aesthetic services and nonuse services. The REA focuses on two major East Coast estuaries—the Chesapeake Bay and the Neuse River. Both estuaries receive between 20 to 30 percent of their annual nitrogen loadings through atmospheric deposition, and both show symptoms of eutrophication.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
NO_x	•estuarine eutrophication	•biomass of harvestable fish •recreational opportunity •wildlife viewing	•changes in food supply •recreation experiences •aesthetic experiences

Terrestrial Nutrient Enrichment

In this section, nutrient enrichment refers only to the enrichment resulting from NO_x deposition because, at this time, the NAAQS applies only to oxidized forms of nitrogen. Although only the detrimental effects of NO_x deposition are discussed here, NO_x deposition in managed terrestrial ecosystems has a beneficial effect: increased growth (a fertilization effect).

The ecosystem services affected by terrestrial nutrient enrichment in unmanaged ecosystems are primarily cultural and regulating services. In CSS areas, concerns focus on a decline in CSS and an increase in non-native grasses and other species, impacts on the viability of listed species associated with CSS and an increase in fire frequency. Changes in mixed conifer forest include changes in habitat suitability, increased tree mortality, increased fire intensity and the forest's nutrient cycling, which may affect surface water quality through nitrate leaching (USEPA 2008). Listed species are protected by the Endangered Species Act. The State of California passed the Natural Communities Conservation Planning Program[37] in 1991, and CSS was the first habitat identified for protection under the program. Only 10 to 15 percent of the original extent of CSS habitat is estimated to remain.[38] Three national parks and monuments in California contain CSS: Cabrillo National Monument, Channel Islands National Park and Santa Monica National Recreation Area. More than a million visitors traveled through these three parks in 2008. Mixed conifer forest is highlighted in Sequoia and Kings Canyon National Park, Yosemite National Park and Lassen Volcanic National Park, where more than 5 million people visited in 2008.

[37] http://www.dfg.ca.gov/habcon/nccp/.

[38] http://www.nps.gov/cabr/naturescience/coastal-sage-scrub-and-southern-maritime-chaparral-communities.htm.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
NO_x	•coastal sage scrub area •mixed coniferous forest area •T&E species habitat quality & area	•recreational opportunity •wildlife viewing	•recreation experiences •aesthetic experiences

B.1.3. Lessons from the Case Study

In the case of the REA (USEPA 2009) and subsequent Policy Assessment for the review of the NO_xSO_x secondary NAAQS (USEPA 2011c), the ecosystem services endpoints provided a frame of reference that helped senior managers and the EPA Administrator understand and discuss the effects of nitrogen and sulfur in the environment in terms that non-ecologists could appreciate readily. To the extent that this analysis quantified the current levels of ecosystem service provision, the assessments characterized their magnitude (e.g., millions of recreational fishers) in a more meaningful way for decision makers than simply describing the effect of nitrogen on lichen community composition. The inclusion of all the ecological effects categories (although the strongest case is for aquatic acidification) enabled managers to consider the full range of possible benefits of each potential alternative standard. In addition, communication materials for secondary NAAQS reviews may be facilitated by the ecosystem services framework, by describing benefits and projected ecosystem improvements in terms that the public may understand more easily than structural or functional ecological endpoints.

B.2. Lampricide Case Study

B.2.1. Policy/Decision Context

This case study focuses on the ecological risks from lampricide applications, which were determined by EPA's ERAs for 3-trifluoromethyl-4-nitrophenol (TFM) and niclosamide that were written in support of the reregistration eligibility decisions (REDs) for these compounds (USEPA 1999). The case study presents the ecosystem services provided by the pesticide registrations. The U.S. Fish and Wildlife Service (USFWS) is the technical registrant for niclosamide and TFM.

Sea lampreys (*Petromyzon marinus*) reside in the Atlantic Ocean but entered the Great Lakes through the New York State Barge Canal and the Welland Canal after its opening in 1829 (USEPA 1999). Larval developmental stages (ammocoetes) of the sea lamprey are bottom filter feeders, whereas the adult is parasitic to fish, attacking commercial and sport fish populations in the Great Lakes, including lake trout, salmon, rainbow trout (steelhead), whitefish, chubs, burbot, walleye, catfish and sturgeon.[39] According to the Great Lakes Fishery Commission website, the incursion of marine lamprey into the Great Lakes had a marked adverse effect on the commercial fishing industry of the Great Lakes. For example, 15 million pounds (lbs) of lake trout (*Salvelinus namaycush*) were caught annually by United States and Canada before the sea lamprey became established, and only 300,000 lbs were landed by commercial anglers by

[39] http://www.glfc.org/sealamp/.

the 1960s. The Great Lakes Fishery Commission was established in 1955 in part because of this decline. In cooperation with Fisheries and Oceans Canada, the USFWS and the U.S. Army Corps of Engineers, the Great Lakes Fishery Commission controls the sea lamprey populations through various pest control methodologies, including physical barriers, traps, release of sterile males and chemical control measures, such as the lampricidal chemicals, niclosamide and TFM.

According to the USFWS (Johnson and Weisser 1996), of the 5,339 tributary streams flowing into the Great Lakes, 309 U.S. streams and 130 Canadian streams have been or are known to have been infested with sea lampreys. Approximately 6 percent (300 U.S. streams) of the total streams have been chemically treated for lamprey infestations since the 1960s. As of 1999 (the year that the USEPA RED was released), 166 streams (less than 3 percent of all tributaries) had received chemical treatment. Approximately 30 to 40 U.S. streams are treated annually, and they do not require retreatment for another 3 to 5 years. From 1993 to 1997, on average approximately 80,000 lbs of active ingredient (a.i.) TFM and 300 lbs a.i. niclosamide were used in the tributary streams of the Great Lakes (see Tables B-1 and B-2). Lampricide applications also have been made in the Finger Lakes of New York and Lake Champlain.

Table B-1. Summary of TFM Use by USFWS in the Great Lakes Region (1993–1997)

	TFM (lbs a.i.)				
Lake	**1993**	**1994**	**1995**	**1996**	**1997**
Superior	6,717	199,91	15,997	12,083	18,768
Michigan	18,150	31,219	25,507	29,811	22,959
Huron	40,371	26,953	24,065	14,605	27,926
Erie	0	9,561	414	59,81	28,15
Ontario	9,438	7,026	10,307	11,001	64,42
Total	74,676	94,750	76,290	73,481	78,910

Source: USEPA (1999).

Table B-2. Summary of niclosamide use by USFWS in the Great Lakes Region (1993–1997)

	Niclosamide (lbs a.i.)				
Lake	**1993**	**1994**	**1995**	**1996**	**1997**
Superior	0	53	114	18	197
Michigan	0	251	53	207	103
Huron	74	33	198	16	89
Erie	0	0	0	0	0
Ontario	7	16	0	33	21
Total	81	353	365	274	410

Source: USEPA (1999).

B.2.2. Summary of the Ecological Risk Assessment

Niclosamide, or Bayluscide®, is a halogenated mononitrobenzamide (CAS Reg. No.: 1420-04-8; CAS chemical name: 2-amino ethanol salt of 2',5'-dichloro-4-nitro salicylanilide; PC Code 217800) that is used to kill ammocoetes. TFM, or Lamprecid®, is a phenol (CAS Reg. No. 88-30-2; CAS chemical name: trifluoro-4-nitro-m-cresol, sodium salt; PC Code 036201) also used to kill ammocoetes. Niclosamide is used in combination with TFM. Granular niclosamide is used where TFM is not appropriate (i.e., deep water) and as a molluscicide to kill freshwater snails. As of the 1999 RED document, seven products containing niclosamide were registered, including as a wettable powder (since 1964), manufacturing use product (1967) and granular (1968). Niclosamide tends to bind to sediment based on average dissociation constant (K_d) values ranging from 1 to 316 in four types of sediments at pH values ranging from 6.5 to 9.0 (Dawson 1986; Dawson et al.1986).[40] In water bodies in which the ratio of water to sediment is large (e.g., lakes), however, much of the compound is expected to remain in the water column and may persist for long periods (aqueous solubility of niclosamide in water: 0.105 mg/L or practically insoluble). Abiotic routes of degradation such as photolysis contribute to dissipation of niclosamide over time, but the extent to which the compound is subject to biotic degradation (metabolism) is uncertain. As such, the extent to which the compound may persist is uncertain; given that tributaries of the Great Lakes are treated, however, the likelihood of dilution is very high, and the applied compounds will dissipate rapidly once in the lake.

Niclosamide is classified as moderately toxic (LD_{50}: 60 mg/kg)[41] to practically nontoxic (LD_{50} > 2,000 mg/kg) to birds on an acute oral exposure basis and is practically nontoxic (LC_{50} > 5,419 mg/kg diet) to birds on a subacute dietary exposure basis. The compound is practically nontoxic (LD_{50} > 1,000 mg/kg) to mammals on an acute oral exposure basis. Niclosamide is highly toxic to very highly toxic (LC_{50} range: 0.03–0.23 mg/L) to freshwater fish on an acute exposure basis. Of the species tested, the most sensitive were rainbow trout, *Oncorhynchus mykiss* (LC_{50} = 0.03 mg/L); sea lamprey (LC_{50} = 0.049 mg/L); and bluegill sunfish, *Lepomis macrochirus* (LC_{50} = 0.049 mg/L). On an acute exposure basis, niclosamide is slightly to very highly toxic (EC_{50}: 0.034 to >50 mg/L)[42] in tests across a range of freshwater invertebrate species (e.g., aquatic earthworms, turbellaria, snails, water fleas, clams, leeches, midges, scuds), with crayfish being least sensitive. On a chronic exposure basis, the no observed adverse effect concentration and the lowest observed adverse effect concentration are 0.03 mg/L and 0.05 mg/L, respectively, for the freshwater invertebrate *Daphnia magna* (water flea). The sensitivity of freshwater plants varied considerably, with EC_{50} values ranging from 0.041to greater than 1,450 mg/L in tests of various species, including diatoms (*Skeletonema costatum*, *Amphiprora paludosa*, *Phaeodactylum tricornutum*) and green algae (*Ankistrodesmus falcatus*, *Scenedesmus quadricauda*), with EC_{50} values ranging from 0.043 to 0.13 mg/L. Furthermore, in aquatic systems, the toxicity of niclosamide is pH and temperature dependent. This issue is important because relatively minor fluctuations in pH can have a marked impact on toxicity. Accordingly, the diurnal shifts in pH that result from fluctuations in dissolved oxygen can cause differences in the extent of nontarget animals affected.

TFM is registered as a liquid formulation (since 1964) and a bar formulation (1984). TFM does not readily bind to sediment (average dissociation constant values range from 0.16 to 11.7 in four sediments at pH values of 6 and 8) and thus will be distributed in the water column.[43] Similar to niclosamide, however, sorption is pH dependent (binding decreases with increasing pH).[44] Much like niclosamide, the

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[40] For niclosamide, mobility increases with increasing pH.

[41] LD_{50} is the amount of an ingested substance that kills 50 percent of a test sample.

[42] EC_{50} is the concentration of a substance that kills 50 percent of a test sample.

[43] Aqueous solubility of TFM: 5,000 mg/L (i.e., soluble in water).

[44] At lower pH, TFM is more toxic, which has implications for mitigation efforts (i.e., application rates that are site specific) that depend on stream pH.

extent to which TFM will persist in lentic environments is uncertain; however, it is expected to dissipate rapidly given the magnitude of dilution present in the Great Lakes.

TFM is classified as moderately to slightly toxic (LD_{50} range: 250–546 mg/kg) to birds on an acute oral exposure basis and is practically nontoxic to birds (LC_{50} > 5,000 mg/kg diet) on a subacute dietary exposure basis. The compound is moderately toxic (LD_{50} > 141–160 mg/kg) to mammals on an acute oral exposure basis. Of all animal groups tested, the only chronic data available are for mammals (a three-generation rat study) for which no mortality or reproductive effects were observed up to the limit test concentration (no observed adverse effect concentration > 5,000 mg/kg diet). TFM is classified as slightly to moderately toxic (LC_{50} range: 3.8–22.3 mg/L) to freshwater invertebrates (including the orders Trichoptera, Diptera, Annelida, Ephemeroptera, Mollusca, Isopoda, Decapoda and Amphipoda). For TFM, the sensitivity of aquatic plants (including diatoms, blue-green algae and green algae) was less variable than for niclosamide, with EC_{50} values ranging from 1.2 to greater than 15 mg/L. TFM is slightly to highly toxic (LC_{50}: 0.60–37 mg/L) to freshwater fish on an acute exposure basis. Of the species tested, the most sensitive was the channel catfish, *Ictalurus punctatus* (LC_{50} range: 0.60–0.75 mg TFM/L; LC_{50}: 0.615 mg TFM + niclosamide/L; Bills and Marking [1976]). The least sensitive species of freshwater fish was the bluegill sunfish (LC_{50}: 37 mg/L). Differential sensitivity to TFM was noted for native versus invasive lamprey larvae; the following species are ranked in order of increasing sensitivity: American brook lamprey (*Lampetra appendix*), northern brook lamprey (*Ichthyomyzon fossor*) and the targeted sea lamprey (King et al. 1985). Studies suggest that a mixture of TFM and niclosamide leads to greater than additive effects in fish and aquatic invertebrates (i.e., the mixture is more toxic than each compound tested alone). Furthermore, mixtures lead to a disproportionately greater increase in sensitivity in sea lampreys relative to aquatic invertebrates. This effect has implications for mitigation. For example, using a mixture of TFM and niclosamide increases the specificity for the invasive sea lamprey larvae versus nontarget species. In addition to population monitoring data, treatment application rates and formulation types for the lampricides are determined by pH level, stream discharge rates, time of day and temperature and involve relatively detailed standard operating procedures and carefully orchestrated applications in which environmental conditions are monitored continuously and treatment rates adjusted accordingly to minimize effects to nontarget organisms.

Risk quotient (RQ) method

Given estimates of exposure based on maximum treatment concentrations (i.e., 25–35 µg a.i./L of niclosamide and 0.7–2.2 mg a.i./L of TFM) in aquatic ecosystems, the values are divided by the ecotoxicity endpoints for the given species to derive RQs (RQs = exposure/toxicity). The RQs then are compared to the Office of Pesticide Program's (OPP) levels of concern (LOCs) to determine potential risk to nontarget organisms and subsequent regulatory action.

Risk Conclusions

<u>Terrestrial</u>

No acute or chronic risks to mammals and birds, which also are surrogates for reptiles and terrestrial-phase amphibians, are expected as a result of use of either TFM or niclosamide; that is, calculated acute RQs are less than 0.1. Although chronic RQs were not calculated, risk is not expected given low toxicity on an acute basis and a chronic basis (e.g., available data include a three-generation rat study for TFM). Neither chemical is expected to bioaccumulate in aquatic organisms, and thus, neither chemical is expected to bioaccumulate in terrestrial organisms. Exposure, however, is still possible. As the aquatic treatment area is exposed during an approximately 24-hour treatment period, aquatic animals may be incapacitated by lampricide treatments and in turn consumed by opportunistic terrestrial animals. Terrestrial organisms also may consume contaminated water. A study on niclosamide and common tern

(*Sterna hirundo*, a listed bird in Michigan), however, determined that the bird would need to consume approximately 16.8 times its body weight in contaminated food (e.g., ammocoetes) to reach toxic levels (Hubert et al. 1999).

Aquatic

Acute risk LOCs for freshwater fish are exceeded for the lampricidal use of TFM, niclosamide and the mixture of the two. Chronic toxicity data for freshwater fish for TFM and niclosamide were not available. Acute risk LOCs are exceeded for freshwater invertebrates for TFM, niclosamide and the mixture of the two. Furthermore, bottom-dwelling (benthic) invertebrates may be at greatest risk to TFM/niclosamide mixture treatments given the propensity of the compounds to partition to sediment under certain conditions; niclosamide is more likely to partition to sediment, however, whereas TFM is more likely to remain in the water column. Given that the persistence of TFM or niclosamide is uncertain, potential exposure of aquatic organisms to the compounds, especially downstream of the treatment site, and subsequent effects cannot be characterized.

Plants

Aquatic plant LOCs are exceeded for TFM use, but not for niclosamide.

Endangered Species

LOCs for risk to federally listed species are exceeded for freshwater fish and aquatic invertebrates for TFM and niclosamide. In addition, the listed aquatic plant LOC is exceeded for TFM. Mitigation for endangered species includes minimizing treatment concentrations at the application sites where listed species are known to exist.

Mitigation

Potential ways to mitigate risk include varying the treatment rate based on pH; applying lampricides to lower reaches of streams where sea lampreys may be localized, consequently permitting upper-reach, native lamprey populations to repopulate lower reaches post-treatment; use of a co-formulation of TFM and niclosamide (more efficacious on target species); and treating affected streams every 3 to 5 years. Treatment efforts rely on stream flushing action to dissipate treatment sites and dilution in the Great Lakes proper.

Uncertainties

Niclosamide and TFM are applied to flowing water, and treatments typically last approximately 12 hours (i.e., treatment areas are raised to and maintained at the desired treatment concentration for 12 hours). Although neither chemical is expected to bioaccumulate in aquatic organisms, long-term effects to aquatic communities, especially indigenous lampreys and communities downstream of the application site, and effects on aquatic food web structure and terrestrial predators, are uncertain. Important to note, however, is that native lampreys tend to be located in higher reaches of streams, whereas sea lampreys tend to be located in the lower reaches close to the mouth of the stream. Limited migration of the sea lampreys into streams typically leaves large areas upstream available for native lamprey populations, effectively facilitating immigration and repopulation of nontarget populations in the treated regions. Indeed, studies suggest that a quick recovery of community structure (within approximately 6 months of treatment) at treatment sites is possible (Kolton et al. 1986). Additional information on effects to nontarget organisms is available from incident reports of adverse effects following applications to tributaries of the Great Lakes, Lake Champlain and the Finger Lakes. For example, within a 4-year timespan (1994–1998), 32 species of fish, 4 species of amphibians and 4 species of invertebrates experienced mortality after applications of niclosamide and TFM (see Table B-3). Despite attempts to avoid mortality to nontarget species, natural pH shifts to acidic levels at particular locations and certain application methods occasionally lead to large fish kills: 33,000 indigenous American brook lamprey (*Lampetra appendix*) and silver lamprey (*Ichthyomyzon unicuspis*) combined (1994, Ausable River system, a tributary of Lake Champlain). Effects on communities downstream of the application site where compounds are discharged, however, are unclear. The lampricide flows from targeted treatment site into large volumes of receiving waters, where it is diluted and dissipated; however, a comprehensive understanding of the environmental fate of these compounds in terms of abiotic and biotic degradation remains unclear.

Table B-3. Nontarget species/taxa experiencing mortality when lampricide in applied to streams and deltas of streams tributary to the Great Lakes, Lake Champlain and the Finger Lakes of the United States (1994–1998)

Invertebrates			
annelids	Phylum Annelida (segmented worms: earthworms, aquatic worms, and leeches)	burrowing mayflies	Family Ephemeridae (burrowing mayflies)
Hexagenia	*Hexagenia spp.*	Mayflies	Order Ephemeroptera (mayflies)
Amphibians			
frogs	Family Ranidae (frogs)	salamanders	Order Candata (salamanders)
Northern two-lined salamander	*Eurycea bislineata*	red-spotted newt	*Notrophthalmus viridescens viridescens*
Fishes			
American brook lamprey	*Lampetra appendix*	banded killifish	*Fundulus diaphanus*
blackchin shiner	*Notropis heterodon*	blacknose dace	*Rhinichthys atratulus*
bluegill	*Lepomis macrochirus*	brown bullhead	*Ameiurus nebulosus*
bullheads	*Ameiurus spp*	common carp	*Cyprinus carpio*
common shiner	*Lusilus cornutus*	creek chub	*Semotilus atromaculatus*
emerald shiner	*Notropis atherinoides*	hornyhead chub	*Nocomis biguttatus*
johnny darter	*Etheostoma nigrum*	largemouth bass	*Micropterus salmoides*
logperch	*Percina caprodes*	longnose dace	*Rhinichthys cataractae*
mimic shiner	*Notropis volucellus*	minnows	Family Cyprinidae (carps and minnows)
Northern hog sucker	*Hypentelium nigricans*	perches	Family Percidae (perches)
redhorses	*Moxostoma spp.*	rock bass	*Ambloplites repestris*
silver lamprey	*Ichthyomyzon unicuspis*	smallmouth bass	*Micropterus dolomieu*
spottail shiner	*Notropis hudsonius*	stonecat	*Noturus flavus*
suckers	Family Catastomidae (suckers)	tadpole madtom	*Noturus gyrinus*
tessellated darter	*Etheostoma olmstedi*	trout perch	*Percopsis omiscomaycus*
white sucker	*Catostomus commersoni*	fishes	Osteichthyes (boney fish)

Source: USEPA (1999).

B.2.3. Ecosystem Services and Benefits

A formal benefits (benefit-cost) analysis was not conducted for TFM and niclosamide for the RED document (USEPA 1999); USFWS has provided an informal benefits analysis, however, which implies that sea lampreys have had a destructive impact on commercial and sport fish species in the Great Lakes. According to USFWS, a variety of population control measures (e.g., integrated pest management strategies such as traps, weirs, sterilized male programs) have provided limited success, and TFM/niclosamide treatments remain an essential control measure to protect commercial and sport fish populations. The ecosystem services discussion, however, goes further. The use of lampricides to control sea lamprey populations in the Great Lakes region has benefits and disadvantages for the aquatic ecosystem. In addition to other population control measures, the lampricides control an invasive species that, if left unchecked, would seriously compromise commercially valuable fish populations and the fisheries that have developed around them. Therefore, if the chemical is not used, the invasive lamprey has the potential to destroy the ecosystem services of commercial and recreational fish as it has done in the past. At the same time, however, nontarget freshwater fish and invertebrate populations (including listed species) are potentially at risk on a limited spatial scale because of lampricide use, particularly at treatment sites and areas immediately downstream of treatment sites. Lampricide use may lead to localized reductions in aquatic animal populations (lampreys and nontarget organisms) from direct toxic effects on adults and developmental effects on larvae leading to mortality (i.e., abnormalities, susceptibility to predation, inability to forage). Aquatic plants (including listed species) provide habitat and food for secondary producers and a source of energy up the food web, but they also may be at risk because of lampricide use. Furthermore, using these lampricides may affect some ecosystem services reliant on native fish and aquatic plant species on a spatially and temporally limited basis but over the long-term would permit the reestablishment of these services. Therefore, not only is the sea lamprey itself capable of disturbing the aquatic food web of the freshwater lake system but also the pesticide used to control it, particularly at the treatment sites and areas that are directly downstream. Nevertheless, decades may be required for a commercial or a sport fishery to recover from sea lamprey infestation across all of the Great Lakes compared to relatively confined spatial and temporal disruptions from the direct effects of the lampricides on aquatic communities.

Some of the ecosystem services provided by the lakes, freshwater fish, invertebrates and aquatic plants are food, nutrient cycling (e.g., carbon sequestration), recreation (e.g., water sports, swimming) and commerce (e.g., shipping, fishing). Whether directly (fishing) or indirectly (e.g., movement of energy up the trophic levels to shorebirds and waterfowl), humans rely on the Great Lakes for food and recreation. In addition, mammalian species (including muskrats, beavers and raccoons) that rely on the ecosystem for nesting and feeding might be exposed to contaminated waters. Risk is not expected for mammals, however.

Invertebrates filter the water, adding to the esthetic and water quality benefits of the lakes. Given minimal chronic toxicity and chemical fate data, long-term effects to these taxa from lampricide uses are unclear; however, population monitoring, alternative sea lamprey control measures and control of pesticide use could mitigate risk to these taxa. Furthermore, the benefit of lampricide uses to control sea lamprey populations to minimize effect on the ecosystem service of commercial and recreational fish may outweigh the risk to nontarget populations of fish and aquatic plants.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
lampricides	•non-target species mortality	•biomass of harvestable fish •recreational opportunity	•changes in food supply •recreation experiences

B.2.4. Lessons from the Case Study

This ERA included conventional measures of effect (i.e., toxicologically relevant endpoints ascribing a lethal dose or lethal concentration expected to lead to 50 percent mortality) that are applicable to the Agency's assessment endpoints of impaired growth, survival and reproduction, which are known to have population-level effects. Because these measures of effect are collected on individual animals, however, linking them to impacts on populations, communities and ecosystems can still be a challenge. Nevertheless, the conventional endpoints and risk conclusions based on them can inform higher-scale (e.g., population, ecosystem) assumptions of risk with an unspecified degree of uncertainty. Furthermore, to extrapolate to a broader level of biological organization, a holistic, weight-of-evidence approach is required. For example, the risk assessment typically includes incidence data (i.e., effects to nontarget organisms that may or may not be attributed directly to a pesticide use) that may be used to support risk estimates based on laboratory data (i.e., toxicity endpoints). In addition, ascribing ecosystem services to organisms directly or indirectly at risk helps develop a larger-scale risk picture that links an effect on a taxon to impacts on human populations. The ERAs completed on the lampricides, particularly the RED document used for this case study, did not consider ecosystem service endpoints, however, in assessing the potential benefits-costs of lampricide use in Great Lakes ecosystems that are cogent to risk management decisions. This ERA might have benefited from additional evaluation of ecosystem services, such as biomass of harvestable fish and habitat quality. Additional evaluation may have tied the use of lampricides to endpoints that humans' value, such as impacts to food production and recreational opportunities, and to nonuse values, such as the cultural and esthetic opportunities offered by the tributary and lake ecosystems.

Not only is the scaling issue difficult to overcome because of data limitations (e.g., individual-level endpoints, single surrogate species for multiple taxa, minimal number of replicates of test groups in a given toxicity study), but also any risk conclusions at higher levels of biological organization have increased uncertainty, especially within the context of an open system for which monitoring data may or may not be available. The use of lampricides in the tributaries of the Great Lakes is not an isolated event; rather, it occurs within the context of various environmental factors (e.g., pH, temperature, climate) and cultural practices (e.g., fishing, recreation, agricultural runoff) that contribute to changes and fluctuations in aquatic organism populations. An example of other invasive species control measures is the effort to prevent the Asian carp from entering Lake Michigan by applying the piscicide rotenone. Lampricides and rotenone also have been identified specifically in listed species recovery plans developed by USFWS. These activities and others confound the determination of risk to given taxa solely based on one stressor (i.e., pesticide). Nevertheless, the conclusions within the context of the ERA written in support of the particular RED document (USEPA 1999) are based on a single stressor to simplify calculations and set a baseline from which to address potential impacts to nontarget organisms. Important to note, however, is that the lampricides (and piscicides) have very elaborate standard operating procedures that attempt to account for several environmental factors (stressors) to reduce potential effects on nontarget organisms.

The standard operating procedures are part of the pesticide label and as such must be followed. These procedures are intended to reduce exposure (and hence risk) to nontarget organisms. The lampricide applications are heavily orchestrated events, and real-time monitoring is an important component. Pre- and post-treatment surveys also are important components of the treatment plans. If listed species are present, care is taken to reduce effects.

B.3. Case Study of Stream Invertebrates Affected by Elevated Salinity

B.3.1. Policy/Decision Context

The leaching of overburden from surface coal mines in Central Appalachia results in elevated salinity and subsequent effects on stream invertebrates (Pond et al. 2009; USEPA 2011a). In response, the Agency developed a benchmark value for specific conductivity of 300 μS/cm (USEPA 2011b). This value was developed by a type of risk assessment (a criterion assessment) that estimates exposure levels corresponding to a prescribed effect (Suter and Cormier 2008). Like the National Ambient Water Quality Criteria, the benchmark was derived using a species-sensitivity distribution. This assessment used the distribution of conductivity levels that cause extirpation of macroinvertebrate genera in the field, however, rather than standard toxicity test endpoints. In the absence of a benchmark, conductivity levels in streams downstream of surface mines reach thousands of μS/cm, which is sufficient to reduce significantly the abundance and diversity of stream invertebrates. The benchmark was used in the detailed guidance to the states and EPA regions on CWA reviews of Appalachian surface coal mining operations (Stoner and Giles 2011).

The assessment endpoint—protection of 95 percent of invertebrate genera from extirpation—is conventional and has been judged equivalent to a standard chronic water quality criterion (SAB 2011). Therefore, it is an adequate endpoint, supported by policy and precedent as a means of meeting the CWA's mandate to restore and maintain the biological integrity of the Nation's waters. Some decision makers and stakeholders have questioned, however, why stream macroinvertebrates are important. Because many of the sensitive genera are mayflies (Ephemeroptera), the question particularly has been focused on that order. Hence, this addendum to the conductivity benchmark assessment describes the benefits lost when aquatic invertebrate genera are lost from Central Appalachian streams.

B.3.2. Ecosystem Services and Benefits

The services and associated benefits of stream macroinvertebrates fall into three categories: they serve as food for fish and other organisms, they perform ecosystem functions such as nutrient retention and they are used by humans in fly-fishing and other activities.

<u>Stream Invertebrates Are Food</u>

The primary ecosystem service of stream macroinvertebrates is as food for fish and other vertebrates that are valued by humans. Hence, this is an intermediate ecosystem service.

Fish provide beneficial ecosystem services, including recreational, cultural, aesthetic, biodiversity and food production. The Appalachian coal region is a center of fish biodiversity, and the seven listed species of fish that occur in the region are insectivores (USEPA 2003). With few exceptions (e.g., stone rollers), fish in streams depend on macroinvertebrates. In particular, macroinvertebrates are the principal food for the game fish that occur in Appalachian streams (brook, rainbow and brown trout). Trout in Appalachian (and other) streams appear to be food limited, and although terrestrial insects contribute, aquatic invertebrates dominate their diets (Allan 1981; Cada et al. 1987; Richardson 1993).

Amphibians provide beneficial ecosystem services, including recreational, cultural, biodiversity and aesthetics. Nearly 10 percent of the global diversity of salamanders occurs in southern Appalachia (Green and Pauley 1987). As larvae, stream salamanders depend on stream macroinvertebrates, and adults may feed on stream or terrestrial invertebrates (Burton 1976). In a headwater Appalachian stream, salamander production was limited by the availability of prey (Wallace et al. 1997).

Birds provide beneficial ecosystem services, including recreational, cultural and esthetic. Bird watching is an important recreational activity, and the sight and sounds of birds are valued by most people. The Louisiana water thrush and spotted sandpiper feed on the aquatic macroinvertebrates in Appalachian streams. Other birds—such as dippers, harlequin ducks and pied-billed grebes—feed on aquatic macroinvertebrates in other habitats. Many other birds such as swallows, warblers and flycatchers feed on the emergent phases of aquatic insects. In one temperate deciduous forest, 25.6 percent of the annual energy budget of insectivorous birds comes from emergent stream insects (Nakano and Murakami 2001). Birds consumed 57 to 87 percent of insects emerging from a prairie stream (Gray 1993). In addition, herons and kingfishers benefit indirectly from macroinvertebrates when they feed on fish and amphibians.

Bats provide recreational, cultural, agricultural and esthetic ecosystem services. Bats feed on the emergent stages of aquatic insects. A recent study of little brown bats found that they feed mainly on aquatic insects, particularly mayflies (Clare et al. 2011). One mayfly genus, *Caenis*, comprised approximately 32 percent of the items in their diet; and during the maternity season, 66 percent were mayflies.

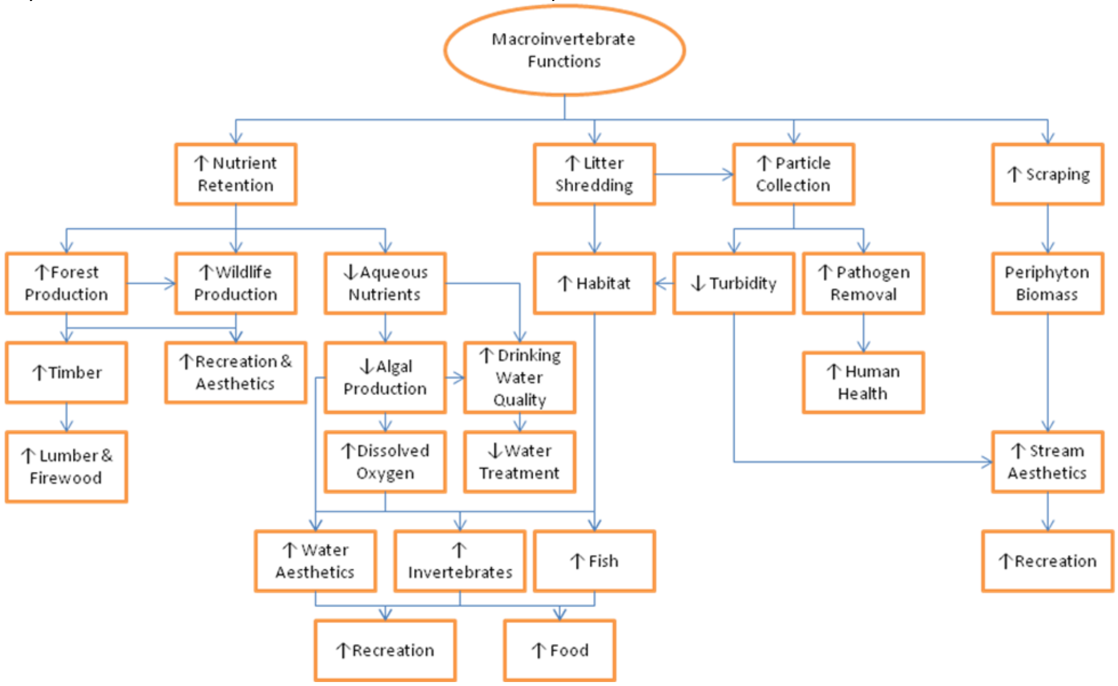
Other aquatic insectivorous mammals provide recreational, cultural and esthetic ecosystem services. Mammals that feed on aquatic macroinvertebrates include water shrews, raccoons, mink and otters. The American water shrew (*Sorex palustris*) in particular is associated with mountain streams and subsists primarily on aquatic insects and crustaceans. The West Virginia subspecies (*S. palustris punctulatus*) is listed as threatened in Pennsylvania (Butchkoski 2010). This status has been attributed to the loss of macroinvertebrate prey from acid mine drainage (PADCNR 2013), but the State of West Virginia states that water shrews are vulnerable to the loss of invertebrates resulting from poor water quality in general (WVDNR 2004).

<u>Stream Invertebrates Perform Ecosystem Functions</u>

Aquatic macroinvertebrates perform various functions in streams that are equivalent to intermediate ecosystem services (Figure B-1). Because the endpoint attribute for this assessment is extirpation of a proportion of the macroinvertebrate assemblage, considering the effects of biodiversity loss on ecosystem functions is important. In general, the loss of biodiversity reduces rates of ecosystem functions and resulting structural attributes such as biomass (Cardinale et al. 2006; Hooper et al. 2005). The ecosystem functions performed by stream invertebrates include:

- **Nutrient Retention:** Invertebrates retain nutrients in their biomass that otherwise would be carried downstream (Evans-White et al. 2005; Jackson and Resh 1989; Newbold et al. 1982, 1983; Wallace and Webster 1996). In an Appalachian stream, macroinvertebrates contained 25 percent of the phosphorus (Newbold et al. 1983). When insects emerge, less than 20 percent, and in some cases as little as 1 percent, return to the stream (Huryn and Wallace 2000). Therefore, nitrogen, phosphorus and other nutrients are returned to terrestrial ecosystems. Nutrient retention is mechanistically linked to at least three ecosystem services: (1) increased productivity of forests and other terrestrial ecosystems, which increases the many services of those ecosystems; (2) improved water quality in the stream, enhancing native oligotrophic biota and improving the quality of recreation; and (3) reduced downstream eutrophication. Overall, this should increase fish and fisheries and reduce the costs of water treatment for algae and algal toxins.

Figure B-1. Conceptual model of the beneficial functions performed by stream macroinvertebrates
Key: Arrows indicate increases ↑or decreases ↓ in ecosystem services or other attributes.



- **Litter Decomposition:** The shredder and collector feeding guilds are important to leaf decomposition in streams (Anderson and Sedell 1979; Short and Maslin 1977; Wallace and Webster 1996; Wallace et al. 1982). Shredders reduce leaves to particles that are consumed by collectors such as net-feeding caddisflies. Together, they increase fish habitat and improve esthetics in small forest streams that would otherwise fill with slowly decomposing leaves. Also, without detritivorous macroinvertebrates, the gravel substrates of forest streams would fill with partially decomposed leaves, which would reduce habitat for salamanders, and for fish eggs and larvae, and would decrease interstitial dissolved oxygen.

- **Cleaning Rocks:** Scrapers remove periphyton from rocks, thereby reducing the amount of "scum" and increasing the productivity of the remaining algae and other microbes (Figure B-2). For example, Yasuno et al. (1982) and Nakano et al. (1999) found that periphyton biomass greatly increased when stream insects were extirpated by a pesticide treatment or were depleted by increased fish predation. Scrapers therefore improve the esthetics of streams for recreationists and decrease the likelihood of falling while wading. In highly productive streams, scrapers may prevent periphyton from cementing the gravel and reducing habitat for fish and salamanders.

- **Participation in Elemental Cycles:** In addition to retaining nutrients, stream invertebrates participate in the transformation of nutrient elements (Mulholland et al. 1991; Newbold et al. 1982). Nutrient cycling is essential to all the services performed by ecosystems.

- **Stabilization of streambeds:** Although freshwater mussels are the most well-known stabilizer of streambeds, colonies of caddisflies also perform that function and are more common, especially in stressed systems. In experimental stream channels colonized with net spinning caddisflies, 10 to 30 percent stronger currents were required to erode sediments than in those without caddisfly colonies (Cardinale et al. 2004). As a result, at velocities that scoured 87 percent of particles from control channels, 0–43 percent of particles were scoured in channels colonized by the caddisflies. Reduced sediment erosion and suspension stabilizes habitat for other benthic species, including lithic spawning fish, and reduces the frequency of which organisms are scoured. Presumably, it also decreases downstream-suspended sediment levels, thereby benefiting fish and humans.

Figure B-2. An advancing "herd" of *Apistomyia* cleaning a rock
Photo by Gregory W. Courtney, courtesy of the Society for Freshwater Science.

- **Removal of Pathogenic Microbes:** Collectors remove algae and microbes from the water column and consume them. Although no studies of collectors focus on pathogen removal, they likely perform this function. This issue is particularly germane in Central Appalachia where some residences have inadequate sewage treatment. Different species are most effective at different flow velocities (Georgian and Wallace 1981) and at capturing different-sized particles (Wallace and Merrit 1980), again illustrating the importance of diversity. Insects can clear water at remarkable levels. In a study of a headwater stream, fluorescently labeled bacteria were removed in less than 100 m, but only 7 percent of uptake was performed by invertebrates with 91 percent by the filter feeding blackfly, *Simulium* (Hall et al. 1996). However, scrapers and shredders, such as the mayfly *Epeorus* and the stonefly *Tallaperla*, respectively also ingested the bacteria, presumably from biofilms. In different circumstances, simuliid larvae removed about 60 percent of cellular algae from a lake outlet in less than a half kilometer of stream (Maciolek and Tonzi 1968). These rates are load- and insect-density dependent (Ladle et al. 1972; McCullough et al. 1979).

Stream Arthropods Have Direct Human Uses

Some benefits of macroinvertebrates are from direct services that are not mediated by functions or by support for other species or biotic communities.

- **Fishing:** In addition to providing food for fish, macroinvertebrates are essential to some types of fishing. Fly fishers rely on stream invertebrates as models for their lures, and insect emergences are occasions for their activity. Many specific mayfly and stonefly hatches are renowned and can draw large numbers of fly fishers from substantial distances, resulting in additional tourism and equipment sales. Bait fishers use macroinvertebrates as bait.

- **Creeking:** Stream invertebrates are an important component of this recreational activity of children and even the occasional adult. Creeking involves exploring a stream and picking up rocks to see what is on or under them. The equivalent activity in ponds and lakes typically involves a net and is called "critter dipping."

- **Indicators:** Stream invertebrates, particularly mayflies, are indicators of water quality and are used for that purpose by the states in the region of concern. Nearly all biological indices of water quality include the number or relative abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa (Barbour et al. 1999; Davis and Simon 1995). For example, the West Virginia Department of Environmental Protection performs bioassessments based on a macroinvertebrate index, the West Virginia Stream Condition Index, which contains percentage EPT and EPT abundance. Macroinvertebrates are more suited to this purpose than fish or other stream biota because they are easily sampled, highly diverse and have a wide range of sensitivities to various agents.

- **Collecting and Watching:** Some individuals and organizations collect and study stream insects recreationally, particularly the Odonata (dragonflies and damselflies). Fanciers collect, catch and release or simply watch odonates, a pastime called oding or dragonflying (see the website *Odes for Beginners*[45] or blogs of individual fanciers, such as Dragonfly Eye). Organizations include the Ohio Odonata Society and the Dragonfly Society of the Americas. Other orders, however, also have fanciers (see the Amateur Entomologists' Society and Mayfly Central, which is for "general users and enthusiasts").

- **Photography:** Photographing insects has become a hobby for some individuals. Examples include the BugShot 2011 event, websites devoted to photographs and the numerous photographs contributed to Mayfly Central and Odonata Central.

- **Literary images and metaphors:** Mayflies have been used as a metaphor for the brevity of life. Numerous song lyrics and poems refer to mayflies and a haiku journal is titled *Mayfly*. The latest book by poet laureate of the United States, Billy Collins (2011) contains the lines:

  "It doesn't take much to remind me
  what a mayfly I am"

  A play titled *Time Flies* by David Ives is about a pair of mayflies. This lyrical use of mayflies is illustrated by a poetic commercial video.[46] Other stream macroinvertebrates have occurred in literature but not to the same extent.

- **Commercial and Organizational Symbols:** Mayflies have been used in the names of many companies, products and events to convey lightness, delicacy, grace or other similar property. For example, Nike makes a line of lightweight Mayfly running shoes and Hewlett Packard produced a parallel processing server called the Mayfly. Paris has a Mayfly Symphony Orchestra, multiple bands have mayfly in their names and a Mayfly Free Festival occurs in Oxford, UK. Other stream insects may have utility as commercial symbols (e.g., a software company is named Stonefly Inc.) but only dragonflies rival the mayflies in symbolic value.

- **Arts and Crafts:** Stream insects, particularly Odonata, have provided motifs for artists and crafters. Examples include the often-copied Tiffany dragonfly lampshades and many pieces of jewelry with dragonfly forms by Tiffany, Lalique and others. Caddisfly cases formed from gold, pearls or semiprecious stones are used to make jewelry or sculptures.

45 http://www.odesforbeginners.com/.
46 http://www.youtube.com/watch?v=6FyDSbc9XR0&feature=player_embedded.

- **Education:** Stream insects have been used for education in biology and ecology (Klein and Merritt 1994). The Izaak Walton League (1996), Council for Environmental Education (2003) and others provide resources for education focused on aquatic macroinvertebrates. Educational use of mayflies is sufficiently common that at least one company markets a kit for field studies (LaMotte Co., Leaf Pack Experiments Stream Ecology Testing Kit) and a simple system has been developed for raising them in the classroom.[47] The classroom materials include a conceptual food web model that illustrates some ecosystem services (Figure B-3).

- **Potential Physical/Chemical Value:** What chemicals, structures or processes might be found in these species that will prove useful is not known. For example, the silk produced by filter-feeding caddisflies is extremely strong and sticky when immersed in fresh water.

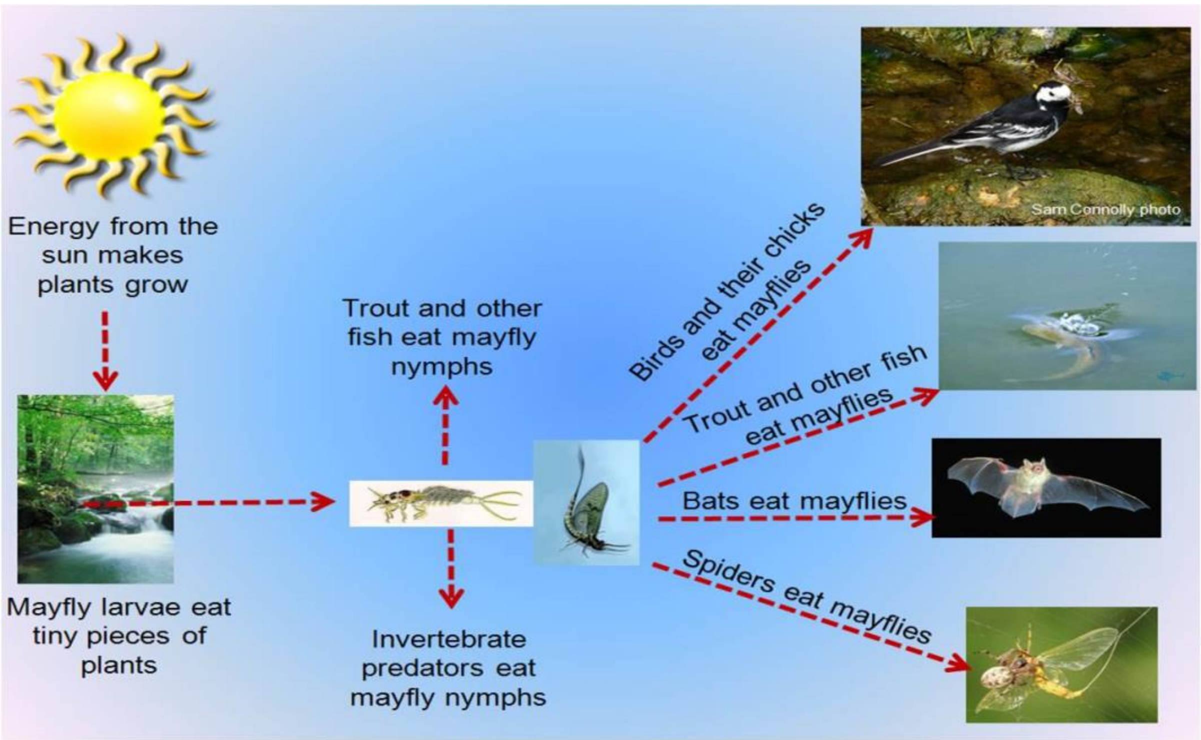


Figure B-3. A conceptual model of the "central role played by mayflies," developed for a classroom program that teaches basic ecology
Source: Gaskell and Gibson (2013).

- **Esthetics:** Stream insects, particularly the dragonflies, mayflies and damselflies, are esthetically appealing to many and add pleasure to recreational outings or everyday experiences. A photographer has reported that prints of the mayfly photograph in Figure B-4 have sold purely because of their esthetics to non-naturalists unfamiliar with mayflies.

Monetary Benefits

Because the benefits of stream macroinvertebrates are largely noneconomic, the CWA does not contain cost-benefit requirements and the decision makers did not ask for monetary values, they were not derived for this case study. Although the benefits of some ecosystem services (e.g., the recreational value of a

47 http://www.mayflyintheclassroom.org/index.html.

trout fishery that depends on macroinvertebrates) potentially are monetizable, the value is context-specific and the necessary data are not available. In addition, it would be extremely difficult to estimate the lost benefits to fishers in the absence of the conductivity benchmark from the increasing losses of macroinvertebrates.

Some related monetary values, however, may be of interest. Mountain trout anglers spent $146 million in North Carolina in 2008 (Responsive Management 2009).

Figure B-4. "Green Drake" mayfly (*Ephemera guttulata*) adult

©2009 D.J. Norton, used by permission.

All anglers spent $333 million in West Virginia in 2006 and 47 percent of those anglers were trout fishers (USFWS 2006). Economic input from use by anglers of a mile of trout stream in West Virginia or Pennsylvania are estimated to range from $28,000 to $74,000 per year (Hansen 2007; Hansen et al. 2008). The monetary benefits of restoring trout waters in Central Appalachia from acidic coal mine drainage range from $1.4 to $73.6 million per year for the Cheat River, Northern Branch of the Potomac River and the West Branch Susquehanna River watersheds (Collins et al. 2009; Hansen et al. 2008, 2010; Williamson et al. 2007, 2008).

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
salinity	•macroinvertebrate occurrence	•recreational opportunity •wildlife viewing •aesthetic enjoyment	•recreation experiences

B.3.3. Lessons from the Case Study

This analysis of the benefits of stream macroinvertebrates is an addendum to the assessment that derived a water quality benchmark for conductivity in Appalachian streams (USEPA 2011b). It did not contribute to the analysis to set the benchmark at 300 µS/cm or the guidance that referenced the benchmark. It answers the question, however, regarding the value and benefits of mayflies and other stream macroinvertebrates. In the authors' experience, a description of a few of the ecosystem services was sufficient to answer the question. In sum, identifying the ecosystem services of stream macroinvertebrates did not improve the decision but did help communicate the soundness of the decision.

In addition to supporting the conductivity benchmark and the detailed guidance, this summary of the ecosystem services of aquatic macroinvertebrates can support other uses of those organisms in assessments and regulatory actions. In particular, most of the biological standards and biological assessments that are used in the CWA Section 305(b) water quality assessment reports and the Section 303(d) lists of impaired waters and Total Maximum Daily Loads are based on macroinvertebrates. Macroinvertebrate monitoring and assessment also may be used in Section 402 National Pollutant Discharge Elimination System permits and Section 401 dredge and fill permits.

The ecosystem services performed by stream macroinvertebrates are not apparent to most people. Even typical stream ecologists are unaware of some of these ecosystem services. Hence, simply describing these ecosystem services can be instructive to assessors, decision makers and stakeholders regarding the importance of preserving macroinvertebrates. Without the macroinvertebrates, streams would be simply channels that support algae and other microbes.

B.4. Threatened and Endangered Species Case Study

B.4.1. Policy/Decision Context

The California Red-Legged Frog (CRLF, *Rana draytonii*, previously *Rana aurora draytonii*) is listed as threatened under the ESA. The ESA was established to "conserve" at-risk species and the ecosystems upon which these species depend.[48] A variety of ERAs are conducted to establish designation of a species as listed, critical habitat for the species and the ultimate goal of delisting a species (which would designate the species effectively recovered for purposes of the ESA). Additionally, ERAs may be performed to examine the effects of actions such as land development or pesticide registration on the persistence of the listed species. In this case study, two ERAs were examined to explore the potential to introduce ecosystem services as possible assessment endpoints. The first ERA was used to designate critical habitat for the CRLF under ESA and the second to evaluate the effect of a pesticide on the CRLF. Although conducting a pesticide registration or reregistration ERA for effects on endangered species under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[49] would be standard practice, in this particular case, the ERA was required as a condition in a legal settlement arbitrating the designation of critical habitat for the CRLF.

The ESA specifies when economic data can and cannot be used in conjunction with an ERA to inform a decision about a species. When a species is a candidate for listing, economic factors *cannot* be considered; and the determination must be "based *solely* on the best scientific and commercial data available."[50] (The 1982 amendment to the ESA added the word "solely" to prevent any consideration other than the biological status of the species.) Congress rejected President Reagan's Executive Order 12291,[51] which required economic analysis of all government agency actions. The House committee opined, "economic considerations have no relevance to determinations regarding the status of

[48] "The purposes of this Act are to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, [and] to provide a program for the conservation of such endangered species and threatened species.", 16 U.S.C. § 1536(a)(1).

[49] 7 U.S.C. § 136 et seq.

[50] 16 U.S.C. § 1355(b)(1)(A).

[51] Exec. Order No. 12291, 46 *Fed. Reg.* 13193 (Feb. 19, 1981).

species" (Stanford Environmental Law Society 2001), thus supporting intrinsic value and nonuse values that are considered under the ecosystem services paradigm.

When critical habitat for listed species is established, however, economic data are allowable.[52] The ESA was amended in 1978 with Congress adding the words "…taking into consideration the economic impact…" in the provision on critical habitat designation (Stanford Environmental Law Society 2001, 23). Consequently, the critical habitat assessment is amenable to the incorporation of monetary valuation of ecosystem services.

The FIFRA statute requires that commercially available pesticides receive ERA screening to determine if they will contribute to the stress on species listed under the ESA.[53] OPP guidance for the conduct of requisite screening, and if necessary, subsequent species-specific assessments, cites FIFRA as introducing economic considerations into risk *management* decisions on pesticide use. FIFRA defines "unreasonable adverse effects on the environment" as "any unreasonable risk to man or the environment, taking into account the economic, social and environmental costs and benefits of the use of any pesticide…" (USEPA 2004). An important distinction is made between risk assessment and risk management, with economic information permitted in making a final management decision, but not a part of the ERA. Worth noting is that use of ecosystem service assessment endpoints can help in determining the economic benefits and costs associated with various decision alternatives.

B.4.2. Summary of the Ecological Risk Assessment

Per EPA ERA guidelines, assessment endpoints are defined as "explicit expressions of the actual environmental value that is to be protected," which are "operationally defined by an ecological entity and its attributes" (USEPA 1998). A provision in Section 4 of the ESA establishes critical habitat as a regulatory link between habitat protection and recovery goals. The primary constituent elements of a species habitat represent the ecological assessment endpoints for ERA:

> "In accordance with section 3(5)(A)(i) of the ESA and regulations at 50 CFR 424.12, in determining which areas to designate as critical habitat, [USFWS/ National Oceanographic and Atmospheric Administration are] required to consider those physical and biological features (primary constituent elements) that are essential to the conservation of the species, within areas occupied by the species at the time of listing, and that may require special management considerations and protection. These include, but are not limited to: space for individual and population growth and for normal behavior; food, water, air, light, minerals, or other nutritional or physiological requirements; cover or shelter; sites for breeding, reproduction, rearing (or development) of offspring; and habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of a species. Habitat loss is the primary threat to most imperiled species, and in 1978, Congress amended the ESA to make critical habitat designation a mandatory requirement for all threatened and endangered species."[54]

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[52] 71 *Fed. Reg.* 71 (Apr. 13, 2006). Section 4(b)(2) of the Act requires the USFWS to designate critical habitat based on the best scientific information available and to consider the economic and other relevant impacts of designating a particular area as critical habitat. The USFWS may exclude areas from critical habitat upon a determination that the benefits of such exclusions outweigh the benefits of specifying such areas as critical habitat. The USFWS cannot exclude such areas from critical habitat when such exclusion will result in the extinction of the subspecies concerned.

[53] 7 U.S.C. § 136 et seq.

[54] 70 *Fed. Reg.* 212 (Nov. 3, 2005), 66911.

Section 4 of the ESA requires that the designation of habitat consider the economic and other relevant impacts[55] "… shall designate critical habitat … on the basis of the best scientific data available and after taking into consideration the economic impact, and any other impact, of specifying … area as critical habitat."[56] The USFWS and the National Oceanographic and Atmospheric Administration may exclude essential areas after taking into consideration the economic impact, impact on national security and any other relevant impact of specifying any particular area as critical habitat.[57]

The effective result of introducing economic considerations into the designation of critical habitat is not to expand the territory of critical habitat, or to strengthen the recovery of the species. To the contrary, the congressional report on the 1978 amendment described the conflict between the new Section 4 additions and the rest of the law: "…the critical habitat provision is a startling section that is wholly inconsistent with the rest of the legislation. It constitutes a loophole that readily could be abused by any Secretary … who is vulnerable to political pressure or who is not sympathetic to the basic purposes of the Endangered Species Act" (Stanford Environmental Law Society [2001], p.68, cites House of Representatives Report 95–1625, at 69 [1978]).

The ESA is silent about how costs and benefits are to be weighed and determined. Presumably, the consideration of economic value always has militated against the incorporation of territory into the listed species' identification of critical habitat. One presumes that economic information pertaining to the economic value of a parcel would be balanced solely against *the value of protecting the species*. This conclusion is not entirely supported by the USFWS response to comments related to the draft economic analysis for the determination of CRLF critical habitat.

In the final rule designating habitat for the CRLF, several of the comments received explore the question of ecosystem service values. Several commenters stated that the draft economic analysis failed to provide a balanced assessment of economic benefits (such as water filtering and general habitat protection) and costs in relation to the revised proposed critical habitat designation.[58] The USFWS responded that its approach for estimating economic impacts includes economic efficiency and distributional effects.

> "The measurement of economic efficiency is based on the concept of opportunity costs, which reflect the value of goods and services foregone in order to comply with the effects of the designation (e.g., lost economic opportunity associated with restrictions on land use). Where data are available, the economic analyses do attempt to measure the net economic impact. However, no data was found that would allow for the measurement of such an impact, nor was such information submitted during the public comment period. *Most of the other benefit categories submitted by the commenter reflect broader social values, which are not the same as economic impacts. (emphasis added)* While the Secretary must consider economic and other relevant impacts as part of the final decision-making process under section 4(b)(2) of the Act, the Act explicitly states that it is the government's policy to conserve all threatened and endangered species and the ecosystems upon which they depend. Thus, we believe that explicit consideration of broader social values for the subspecies and its habitat, beyond the more conventionally

[55] 70 *Fed. Reg*. 212 (Nov. 3, 2005), 66906.

[56] 16 U.S.C. 1533(b)(2).

[57] 16 U.S.C, Section 4(b)(2).

[58] Rules and Regulations: Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the California Red-Legged Frog, and Special Rule Exemption Associated With Final Listing for Existing Routine Ranching Activities, 71 *Fed. Reg.* 71 (Apr. 13, 2006), 19258. http://www.epa.gov/fedrgstr/EPA-SPECIES/2006/April/Day-13/e3344.htm.

defined economic impacts, is not necessary as Congress has already clarified the social importance. We note, as a practical matter, it is difficult to develop credible estimates of such values, as they are not readily observed through typical market transactions and can only be inferred through advanced, tailor-made studies that are time consuming and expensive to conduct. We currently lack both the budget and time needed to conduct such research before meeting our court-ordered final rule deadline. In summary, we believe that society places significant value on conserving any and all threatened and endangered species and the habitats upon which they depend and thus needs only to consider whether the economic impacts (both positive and negative) are significant enough to merit exclusion of any particular area without causing the species to go extinct."

Malathion and the CRLF

The risk assessment for the effects of malathion on the CRLF (USEPA 2007) evaluated the potential for the use of the insecticide malathion to affect the CRLF or modify its designated critical habitat. The assessment was performed pursuant to a court-ordered stipulated injunction following a lawsuit brought against EPA by the Center for Biological Diversity.[59] As part of the stipulated injunction, EPA was required to determine the effects of 66 pesticides (including malathion) on the CRLF within certain areas of California under a court-ordered schedule. In the case of malathion, the ERA identified clear indications that existing uses are "likely to adversely affect the California Red-Legged Frog, based on direct affects to the California Red-Legged Frog and indirect effects to the prey base of the California Red-Legged Frog" (USEPA 2007). Assessment endpoints followed the identification of primary constituent elements used in the ERA for the ESA for determination of critical habitat. Economic considerations were not incorporated in the ERA, but were evaluated as a part of the management decision.

No additional detail is provided here regarding the malathion ERA because economic considerations are not introduced in the ERA. In this instance, the information on the malathion ERA was incorporated into a revised EA, which in turn was included in the final rule[60] for CRLF critical habitat. Comments received regarding ecosystem services in the revised draft economic analysis were considered by the USFWS in its final rule, but they were separate from the ERA. The legal settlement requiring consideration of the malathion ERA in the determination of CRLF critical habitat was atypical for an ERA associated with pesticide effects on a listed species. Typically, such ERAs are initiated as a standard registration or reregistration for a pesticide under FIFRA, and would be evaluated by EPA within the Office of Chemical Safety and Pollution Prevention Registration Division or Pesticide Reregistration Division for considering use restrictions.

FIFRA Section 3 "amendment actions"[61] are screened in the Registration Division or Pesticide Registration Division to determine obvious changes from the current labeled use of a pesticide. Those

[59] Center For Biological Diversity v. Stephen L. Johnson, Administrator, Environmental Protection Agency, and Wayne Nastri, Region 9 Administrator, Environmental Protection Agency, Defendants, and Croplife America, American Forest & Paper Association, Western Plant Health Association, Oregonians for Food And Shelter, and Syngenta Crop Protection, Inc., Defendants-Intervenors, Case C-02-1580-JSW (N.D. California 2006). http://www.epa.gov/espp/litstatus/stipulated-injunction.pdf.

[60] Endangered and Threatened Wildlife and Plants; Revised Designation of Critical Habitat for the California Red-Legged Frog. Final Rule. 75 *Fed. Reg.* 51 (Mar. 17, 2010). http://www.fws.gov/policy/library/2010/2010-4656.pdf.

[61] Section 3 authorizes EPA to register new pesticide products and new uses of existing pesticides in the United States.

actions that indicate a change in use are sent to the Office of Chemical Safety and Pollution Prevention science divisions for review. When the Environmental Fate and Effects Division's (EFED) screening-level ecological risk assessment (SLERA) raises potential concerns related to listed species, EFED conducts a species-specific evaluation to refine the assessment. EFED is routinely notified and has an opportunity to conduct its analysis if potential concerns related to listed species are identified.

After the EFED and (Human) Health Effects Division submit their risk assessments to the Registration Division or Pesticide Registration Division, the risk assessments are reviewed and potential risk mitigation measures that can incorporate economic information can be developed. OPP makes pesticide (re)registration determinations based on the statutory standards of the FIFRA and the Federal Food, Drug and Cosmetic Act.[62] If the application fails to meet these standards, the need for more or better data, labeling modifications and use restrictions are identified and the deficiencies are communicated to the applicant. If the application is approved, EPA establishes a tolerance if the pesticide is intended for use on food or feed.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
pesticides	•critical habitat quality	•recreational opportunity	•recreation experiences

B.4.3. Lessons from the Case Study

The USFWS's response to comments on the draft economic analysis in the final rule designating habitat for the CRLF appears to be an opportunity for introducing ecosystem service valuation as a "positive impact" in making critical habitat designations. Even when economic information is permitted, however, it generally is not a part of the ERA, but rather is introduced as a (draft) EA. Thus, the purpose of introducing ecosystem service ecological assessment endpoints into an ERA to strengthen the crosswalk to economic analysis is not direct, but would be more likened to a crosswalk.

Questions also remain about how far this argument can be advanced. The introduction of ecosystem services valuations on any parcel would probably not be considered as enhancing the identification of the parcel as critical habitat for the recovery of the species, even if the valuation did enhance the argument for protecting the parcel from development and associated economic advantage. The use of ecosystem services valuation to mitigate or balance against other economic factors, however, could change the debate about a parcel's value, which could conceivably affect the listing of a parcel as critical habitat. Whether ecosystem services information will be part of establishing listed species' critical habitat will need to be resolved legally.

Any opportunity for introducing ecosystem services valuation information as an assessment endpoint for the pesticide ERA for the CRLF is not indicated. Economic information was incorporated into a final decision in which the pesticide ERA also was considered—but, as with the ERA for the determination of critical habitat, it was evaluated post-ERA as a part of the management decision. Even when a pesticide ERA is used in the more conventional way to inform pesticide use and restrictions, economic considerations appear to be allowed in conjunction with the final management decision, but are not a

[62] 21 U.S.C. § 301 et seq.

component of the ERA itself. Incorporation of ecosystem service valuation in an ERA or as a part of the economic assessment would enhance analysis. Because the valuation information could correspond (potentially directly) with ecological assessment endpoints in the ERA, the economic analysis could align more closely with the ERA—at least on the points identified through the ecosystem services valuation. The larger question of whether to incorporate ecosystem services as assessment endpoints in an ERA purposed toward pesticide (re)registration would need to be evaluated by OPP.

B.5. Hazardous Waste Site Case Study

B.5.1. Policy/Decision Context

CERCLA, as amended by SARA, authorizes EPA's Superfund program to protect public health and welfare and the environment from the release or potential release of any hazardous substance, pollutant or contaminant. The primary regulation issued by EPA's Superfund program is the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The NCP calls for the identification and mitigation of environmental impacts at contaminated sites and for the selection of removal or remedial actions to protect public health and the environment. An important part of the NCP is the requirement for a Remedial Investigation and Feasibility Study. The Remedial Investigation and Feasibility Study is an analytical process designed to support risk management decision making for Superfund sites.

ERA is an integral part of the Remedial Investigation and Feasibility Study process that determines the potential for adverse effects to the environment based on the chemicals present at the site and their concentrations and distributions. The goal of the ERA process in the Superfund program is to provide the risk information necessary to assist risk managers at Superfund sites in making informed decisions regarding substances designated as hazardous under CERCLA. The functions of the ERA are to (1) document whether actual or potential ecological risks exist at a site, (2) identify what contaminants present at a site pose an ecological risk and (3) generate data to be used in evaluating cleanup options.

B.5.2. Summary of the Ecological Risk Assessment

This New Jersey Superfund site is an abandoned hazardous waste site located in central New Jersey along the Raritan River. It was formerly used as a dump, a metals recovery operation and an industrial property. A residential neighborhood is located approximately one-half mile to the southeast of the site. The site is located on the south shore of the Raritan River. Surface water from the site drains into a fresh water marsh area of approximately 8.2 acres, and this wetland then drains to the Raritan.

One drainage channel collects most of the surface water from the site and appears to provide most of the fresh water flow into the marsh, and the most distinguishable surface water flow through the marsh can be traced to this channel. Approximately 95 percent of the onsite marsh is dominated by common reed (*Phragmites australis*) and is considered a freshwater emergent wetland. The remaining 5 percent is a fringe averaging 25 feet wide at the edge of the Raritan River and dominated by salt-tolerant cordgrass (*Spartina* spp.), indicative of an intertidal wetland environment.

The onsite drainage channel is the most highly contaminated portion of the marsh. Polychlorinated biphenyls (PCBs) are found at highest concentrations in shallow surface sediments of the stream channel and at lower concentrations within the marsh itself and at depth. Arsenic and mercury were found at their highest concentrations within the drainage channel; however, these two metals also were found throughout the marsh and at depth at elevated concentrations. The distribution pattern for arsenic and mercury suggest that these contaminants were discharged into the marsh in a relatively soluble form, allowing dissolved constituents to pass deeper into the marsh sediments before the subsurface geochemistry forced the arsenic and mercury to precipitate.

A SLERA was conducted for the site to determine which contaminants and exposure pathways presented ecological risks based on conservative assumptions. Three primary contaminants of potential concern (COPCs) identified in the marsh and associated drainage ways were arsenic, mercury and PCBs. Receptor species selected to represent the various habitat and trophic levels of the site were the red-tailed hawk (*Buteo jamaicensis*), northern short-tailed shrew (*Blarina brevicauda*), marsh wren (*Cistothorus palustris*), spotted sandpiper (*Actitis macularius*), green frog (*Rana clamitans*), fiddler crab (*Uca* sp.) and the benthic invertebrate community.

The conventional risk assessment endpoints and measures of effect for the SLERA included:

- Protection of the survival, growth and reproduction of aquatic invertebrates from the toxic effects of site-related COPCs measured through comparison of contaminant exposure to contact ecotoxicity values and the protection of upper trophic organisms consuming aquatic invertebrates.

- Protection of the survival, growth and reproduction of mammals that feed on soil invertebrates measured through the comparison of contaminant dietary exposure to dietary ecotoxicity values.

- Protection of the survival, growth and reproduction of birds that feed on the site measured through comparison of contaminant dietary exposure to dietary ecotoxicity values.

- Protection of the survival, growth and reproduction of amphibians measured through comparison of contaminant exposure to contact ecotoxicity values.

Food chain risks were estimated for the modeled receptors (red-tailed hawk, short-tailed shrew, marsh wren, spotted sandpiper) by comparing estimated exposure levels with ecologically based toxicity reference values. Risks to the green frog and fiddler crab were evaluated by comparing surface water concentrations to aquatic toxicological benchmarks. Sediment and surface water contaminant concentrations were compared to ecologically-based screening values to determine risks to benthic invertebrates. The results of the SLERA showed potential for ecological risk at the site as a result of exposure to chemicals detected in site surface water, sediment and surface soil.

A SLERA Addendum was completed to collect additional samples in the marsh and the adjacent river. Forage fish samples were collected to estimate contaminant concentrations in fish tissue. Toxicity tests were conducted at five sampling locations with the amphipod (*Leptocheirus plumulosus*) using a 28-day chronic bioassay. The assessment endpoints and measures of effect used in this addendum are the same as the SLERA, but with the protection of the estuarine fish community taking the place of the amphibian community. Osprey (*Pandion haliaetus*) and herring gull (*Larus smithsonianus*) were added as ecological receptors to represent exposures from consuming estuarine fish species. The SLERA Addendum indicated potential for ecological risk from exposure to chemicals present in the marsh and the portion of the river adjacent to the site. Therefore, a baseline ecological risk assessment (BERA) was warranted.

A BERA uses a four-step process for assessing site-related ecological risks for a reasonable maximum exposure scenario:

- **Problem Formulation:** a qualitative evaluation of contaminant release, migration and fate; identification of COPCs, receptors, exposure pathways and known ecological effects of the contaminants; and selection of endpoints for further study.

- **Exposure Assessment:** a quantitative evaluation of contaminant release, migration and fate; characterization of exposure pathways and receptors; and measurement or estimation of exposure point concentrations and doses.

- **Ecological Effects Assessment:** literature reviews, field studies and toxicity tests that link contaminant concentrations to effects on ecological receptors.

- **Risk Characterization:** estimation of current and future adverse effects of the contaminants.

The conventional risk assessment endpoints in the BERA focused on the following marsh and river ecosystems:

- Aquatic macroinvertebrate community abundance and population production in marsh sediment, relying on laboratory testing of sediment toxicity using a sensitive and representative aquatic macroinvertebrate (*Lumbriculus variegatus*, blackworm) as the measure of effect.

- Terrestrial invertebrate community abundance and population in the marsh sediment, relying on laboratory testing of sediment toxicity using a sensitive and representative terrestrial invertebrate (*Eisenia fetida*, earthworm) as the measure of effect.

- Estuarine fish population abundance and community structure in the Raritan River, relying on measured concentrations of COPCs in the water column compared with state water quality standards and measured COPCs in estuarine fishes of the Raritan compared with literature-based effect-level thresholds as measures of effect.

- Wildlife population abundance in the marsh and the river, relying on modeled dietary doses of COPCs based on measured concentrations of COPCs in prey organisms and in marsh and river sediments, compared with toxicity reference values.

Representative species for the marsh were the short-tailed shrew, muskrat, marsh wren and red-tailed hawk. The species selected for the river were the osprey and the herring gull.

The BERA used aquatic oligochaete and terrestrial earthworm sediment toxicity tests to assess risks to benthic and terrestrial invertebrate communities. Risks to estuarine fish were analyzed by comparing contaminant concentrations in fish tissue to effects-based literature values. Additionally, food web modeling was used to evaluate risks to bird and mammal populations.

The BERA indicated that there might be risks to benthic organisms from contaminated river sediment in the area immediately adjacent to where the main channel from the marsh enters the river. The marsh sediment also was found to pose potential adverse effects on the growth of aquatic and terrestrial invertebrates. Additionally, potential adverse effects on bird and mammal receptor species may be associated with the elevated contaminant concentrations in the marsh sediment. The risk drivers for these ecological receptors were identified as arsenic, mercury and PCBs.

Assessment of Estuarine Fishes

This work was performed during the SLERA and involved comparing COPC concentrations in the surface water against screening benchmarks and comparing COPC concentrations in fish/crab tissue with whole-body residue effects levels. This screening assessment indicated a very low likelihood of adverse effects to estuarine fishes from COPCs in surface water. Although New Jersey has established fishing advisories within the Raritan River as a result of PCB levels that may be found in American eel (*Anguilla* *rostrata*), white catfish (*Ameiurus catus*), white perch (*Morone americana*), striped bass (*Morone saxatilis*), bluefish (*Pomatomus saltatrix*) and blue crab (*Cellinectes sapidus*), locally collected crabs and forage fish have not demonstrated elevated concentrations of COPCs during several different sampling events. The most recent sampling event (crabs and killifish) was associated with the BERA supplemental investigations in 2004.

Assessment of Marsh

Food web model results for short-tail shrew (representing mammals that may feed on insects) suggest arsenic, mercury, PCBs and possibly copper are the primary drivers of ecological risk, and that hazard quotients (a semiquantification of risk) were elevated above the reference areas across the marsh. The magnitude of hazard quotient values generally varied across the marsh in relation to contaminant concentrations. Results for muskrat (*Ondatra zibethicus*, a mammalian herbivore), were averaged over the entire marsh based on a wider home range. Arsenic and mercury appear to be the primary contaminants of concern for muskrat. For the marsh wren (representing insect-eating birds), mercury appeared to be the primary risk driver, along with arsenic and chromium. As with the mammalian indicator species, higher hazard quotients occurred for stations near the marsh channel. Finally, results for the red-tailed hawk (carnivorous bird), that may prey on small mammals within the marsh, did not manifest a likely adverse ecological effect from foraging on the site.

Assessment of River

The food-web modeling of the herring gull and osprey indicated low risk associated with contaminated sediment and surface water in the Raritan River. Beyond a limited benthic community assessment, which indicated some toxicity in sediments probably associated with arsenic and mercury, the ERA attributed little likelihood of a site-specific effect to receptors in the Raritan.

Selected Remedial Alternative

CERCLA requires that nine criteria be used when selecting a remedy, including two threshold criteria (minimum requirements that each response measure must meet to be eligible for selection as a remedy). The threshold criteria are:

1. **Overall protection of human health and the environment:** Overall protection of human health and the environment addresses whether each alternative provides adequate protection of human health and the environment and describes how risks posed through each exposure pathway are eliminated, reduced or controlled through treatment, engineering controls or institutional controls.

2. **Compliance with applicable or relevant and appropriate requirements (ARARs):** Section 121(d) of CERCLA and NCP 300.430(f)(1)(ii)(B) require that remedial actions at CERCLA sites at least attain the legally applicable or relevant and appropriate federal and state requirements, standards, criteria and limitations that are collectively referred to as "ARARs" unless such ARARs are waived under CERCLA Section 121(d)(4). ARARs are those cleanup standards; standards of control; and other substantive requirements, criteria or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance found at a CERCLA site.

Once the threshold criteria have been met, cost is considered a primary balancing criterion or a factor with which tradeoffs between response measures are assessed so that the best option will be chosen, given site-specific data and conditions. CERCLA remedial decisions do not include a cost-benefit analysis.

Based on consideration of the results of the site investigation and risk assessment, the requirements of CERCLA, a detailed analysis of the response measures and public comments, EPA has determined the remedial action to be full excavation and restoration of the marsh and deep dredge and cover for the river sediments. These actions include:

- Excavation, transportation and disposal of approximately 21,000 cubic yards of contaminated sediments from the marsh.
- Dredging an estimated 14,000 cubic yards of contaminated sediments from the Raritan River.
- Dewatering and off-site disposal of excavated/dredged sediments in an appropriate land disposal facility.
- Backfilling and grading of all excavated marsh areas with clean cover material to allow for reestablishment of wetland habitat.
- Filling of the dredged river area with clean cover material that will support the reestablishment of a benthic community in surface sediments.
- Institutional controls in the marsh, such as a deed notice or covenant, to prevent exposure to residual soils that may exceed levels that would allow for unrestricted use that may remain at the completion of the remedial action.
- Institutional controls for the river sediments such as a restricted navigation area, to prevent disruption of cover if contaminated sediments are left at depth.
- Onsite restoration of approximately 6 acres of wetlands disturbed during implementation of the remedy.

The site is zoned for economic redevelopment and light industrial usage. Both uses exclude residential use. The 8.2-acre marsh is not suitable for commercial development and, under any of these future-use scenarios, EPA expects that the marsh will remain open space/ecological habitat.

The selected sediment alternative for the marsh was chosen versus other alternatives because it is expected to achieve substantial and long-term risk reduction through off-site disposal and is expected to enable the property to be used for the reasonably anticipated future land use, which is open space/wetland. The selected marsh remedy reduces the risk within a reasonable timeframe, at a cost comparable to other alternatives and is reliable over the long term.

Case Study Illustration

Stressor	Case Study Ecological Assessment Endpoint	Potential Ecosystem Service Assessment Endpoint	Societal Benefit
chemicals	•aquatic invertebrate survival, growth, and reproduction	•biomass of harvestable fish •recreational opportunity	•changes in food supply •recreation experiences

B.5.3. Lessons from the Case Study

EPA solicited input from the community on the remedial response measures proposed for the site. Oral comments were recorded from attendees of the public meeting and written comments were received via mail. The primary areas of concern expressed in the comments received were (1) the remediation goals for contaminated sediments, and (2) whether the depths of the sediment excavations considered in the proposed plan were appropriate to the site. The comments expressed concerns that EPA had not been sufficiently protective in selecting remediation goals and that the depths of removal were insufficient. Some of the comments indicated that EPA had been overly conservative in assessing the ecological risks and potential for off-site transport of contaminated sediments, such that the preferred remedial alternative was unnecessarily conservative and expensive.

One of the comments stated that the total cost for EPA's preferred alternative was out of proportion to the potential risks associated with the site. The commenter stated that there are no risks to human health because the marsh is covered with *Phragmites*, which is virtually impenetrable by humans, and there are no plans for residential development. The use of ecosystem service assessment endpoints in the ERA could have provided another way for the public to view the proposed remedial measures. The ecosystem service assessment endpoints could have helped the public understand how the restored marsh and remediated sediments indirectly provide benefits to them, including water purification, fishery habitat and flood stage reduction. By looking at the remedial alternatives with an ecosystem service assessment endpoint viewpoint, the public could better understand that excavation and restoration of the marsh will benefit the aquatic and terrestrial invertebrates immediately and the public in the long term.

Identifying the ecosystem services existing at a contaminated site prior to the remediation process can provide valuable insight to the remediation investigation and planning. This knowledge helps establish a baseline that could assist project managers and stakeholders in the creation of a revitalization or reuse plan. This information can be used to complement the protectiveness of the cleanup by providing humans with the benefits of clean water, clean air, recreational opportunities, protection of cultural resources and other benefits.

Assessment endpoints are defined as "explicit expressions of the actual environmental values (e.g., ecological resources) that are to be protected." Valuable ecological resources include those without which ecosystem function would be significantly impaired, those providing critical resources (e.g., habitat, fisheries) and those perceived as valuable by humans (e.g., endangered species and other issues addressed by legislation). Converting these conventional endpoints to ecosystem service assessment endpoints is possible to help the public understand how protection of the environment relates to their well-being and enjoyment.

The aquatic invertebrates serve as food for fish. Decreases in the abundance and population numbers of these invertebrates will decrease the numbers and types of fish that feed on them. This, in turn, will decrease the number and type of fish that people will catch for food and as a recreational activity.

The soil invertebrates convert leaf litter to humus. These invertebrates hasten the decomposition of organic matter and incorporate it into the soil, hasten mineralization, increase nutrient retention and increase the depth of the oxic zone. They also serve as a food source for birds and mammals.

The estuarine fish population serves as sport fish and food for people and is a component of a healthy aquatic habitat. The cleanup of contaminated sediments at the site and in the river will provide the fish a cleaner environment and reduce the amount of contaminants to which they are exposed. This, in turn, will provide for a healthier food source for humans and piscivorous birds and mammals.

Wildlife populations serve as a food source and a resource for hunting and convey religious or cultural relevance for certain human populations—all valued ecosystem services. Their continued abundance also serves wildlife viewing, an ecosystem service enjoyed by many people at small wetlands. The selected remedy to clean up onsite marsh sediments and river sediments and wetlands restoration will bring these areas back to a condition that will not be harmful to the ecological receptors mentioned above and will allow the various ecosystem functions of the site to provide benefits for ecological receptors and humans. Onsite restoration of disturbed wetlands will provide improved wildlife habitat for ecological receptors and afford humans better opportunities for bird watching and wildlife viewing.

B.6. Case Study Literature Cited

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