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A Framework For Assessing and Reporting on Ecological Condition: Executive Summary

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The SAB's principal mission is to review the quality and relevance of the scientific information being used to support Agency decisions, review research programs and strategies, and provide broad strategic advice on scientific and technological matters. In addition, the SAB occasionally conducts special studies at the request of the Administrator to examine comprehensive issues, such as anticipating future environmental risks and developing new approaches to analyze and compare risks to human health and the environment.

Cover photo: The Experimental Lakes Area, a research facility in Ontario, Canada where a number of lakes and watersheds have been set aside for whole-lake manipulation experiments. Photo by C. Gilmour.

A Framework for Assessing and Reporting on Ecological Condition: Executive Summary

Terry F. Young and Stephanie Sanzone, Editors

Prepared by the Ecological Reporting Panel

Ecological Processes and Effects Committee

EPA Science Advisory Board

Washington, DC 20460

September 2002

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, DC 20460

September 26, 2002

OFFICE OF
THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

EPA-SAB-EPEC-02-009A

Honorable Christine Todd Whitman
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Subject: A Framework for Assessing and Reporting on Ecological Condition:
A Science Advisory Board Report

Dear Governor Whitman:

The Environmental Protection Agency, both in the past and under your leadership, has played a prominent role in informing the nation about the condition of its environment. In order to assist you with this effort, the Science Advisory Board (SAB) is pleased to provide you with the attached report, *A Framework for Assessing and Reporting on Ecological Condition*. The purpose of the report is to offer an organizational tool that will assist the Agency systematically to develop, assemble, and report on information about the health of ecological systems. The proposed framework also provides a checklist of ecological attributes that should be considered when designing ecological risk assessments, setting ecological research priorities, and developing ecological management objectives for a broad array of Agency programs.

Driven in part by the Government Performance and Results Act (GPRA), much attention recently has been focused on environmental reporting. At the same time, there is a general desire to shift from reporting on government activities to reporting on the resulting improvements in human and ecosystem health. Both your November 13, 2001 memo calling for a “State of the Environment Report” and the SAB’s 2000 report, *Toward Integrated Environmental Decision-making*, underscore the need for this shift.

From our point of view, better information about ecological condition is a prerequisite for better decision-making about ecological resources generally and Agency mandates specifically. For example, information about an array of ecological characteristics — in addition to the chemical quality of air, water, and soil—can help the Agency and local groups target the highest priority problems, rather than targeting those about which the most data have been collected. This information also can be used by local and state decision-makers to address environmental problems that affect Agency activities but are outside of its direct purview, such as land use planning within watersheds. Similarly, information about ecological condition can help the Agency predict future problems, serving as "leading indicators." The SAB is acutely aware, however, that assessing ecological system health is scientifically complex and difficult to accomplish with limited resources.

Reporting on ecological system health is equally complex, and few good examples currently are available. Although hundreds of relevant ecosystem health indicators exist, little guidance is available for distilling them into a few, credible summary statements for the public. As a result, reports generally contain a selection of indicators that may be important, but seem disjointed even to a casual reader and are not representative of the array of characteristics necessary to assess ecological health. Another important impediment to good reporting is the current dearth of ecological condition data. SAB members often have been struck by the lack of ecological data available outside of a few categories most directly related to the Agency's mandates. Moreover, in a number of reviews conducted by the SAB's Ecological Processes and Effects Committee over the past decade, the Committee noted the Agency's lack of a comprehensive and consistent list of ecological characteristics. This shortcoming has limited the Agency's ability to achieve its program objectives.

These recurring problems, combined with the challenge of creating useful "report cards," provided the impetus for the attached report. *A Framework for Assessing and Reporting on Ecological Condition* provides a checklist of essential ecological attributes that can be used as a guide for designing a system to assess, then report on ecological condition. The list is organized as a hierarchy that allows the user to judge tradeoffs when all attributes cannot be studied. This hierarchy also provides a roadmap for synthesizing a large number of indicators into a few, scientifically defensible categories, each of which sums up an important ecological characteristic. These categories can then be reported on directly or used as the foundation for extracting information related to particular environmental management goals such as the "number of estuaries with healthy, sustainable aquatic communities." Because the framework derives from the principles of ecology and ecological risk assessment, it provides a rigorous basis for collecting and reporting information that covers the characteristics that are essential for understanding and managing ecosystems.

The framework has been road-tested on three Agency programs — a public information tool related to Clean Water Act implementation, a monitoring and assessment research program, and an EPA-state environmental reporting program — and a monitoring program of the USDA Forest Service. Further, the report compares the SAB framework to the suites of environmental indicators recently recommended by the National Research Council and The Heinz Center. The results of these tests indicate that the SAB framework is comprehensive, that it can be used for a variety of aquatic and terrestrial ecosystem types, and that it can be used as a template for synthesizing information from different programs both within and outside the Agency.

In sum, the SAB framework provides a checklist of ecological attributes that should be considered when evaluating the health of ecological systems. It also provides an organizational scheme for assembling hundreds of individual parameters into a few understandable attributes. We hope that the SAB framework will foster more systematic collection of ecological information by the Agency, provide a locus for integrating that information among programs both within and outside the Agency, and catalyze a trend towards environmental reporting that addresses the essential attributes of ecological systems.

Ecological systems are complex, and it has proved extremely difficult to answer the holistic questions that people ask about them — "How healthy is my watershed? Will native species be here for my children and grandchildren to enjoy?" With this report, we provide a way to integrate scientific data into the information necessary to answer these questions, and ultimately to foster improved management and protection of ecological systems. We look forward to your response to this report, and we would welcome the opportunity to discuss these issues further with you as the Agency moves forward with a report on the state of the environment.

Sincerely,

Dr. William H. Glaze, Chair
EPA Science Advisory Board

Dr. Terry Young, Chair
Ecological Reporting Panel
Ecological Processes and
Effects Committee
EPA Science Advisory Board

NOTICE

Distribution and Availability: This EPA Science Advisory Board report is provided to the EPA Administrator, senior Agency management, appropriate program staff, interested members of the public, and is posted on the SAB website (www.epa.gov/sab). Information on its availability is also provided in the SAB's monthly newsletter (*Happenings at the Science Advisory Board*). Additional copies and further information are available from the SAB Staff [US EPA Science Advisory Board (1400A), 1200 Pennsylvania Avenue, NW, Washington, DC 20460-0001; 202-564-4533].

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Science Advisory Board
Ecological Processes and Effects Committee

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INTRODUCTION

Better information about ecological condition is a prerequisite for better decision-making…

A wealth of environmental monitoring information has been developed since the nation first turned its collective attention to improving environmental quality more than three decades ago. Yet many scientists, most decision-makers, and nearly all members of the public still have little understanding of the "health" or integrity of the nation's ecological systems. The monitoring programs tailored to report on the implementation of environmental laws and programs — the cleanup of pollutants, the management of public forests and rangelands, and so forth — may accomplish the intended purpose but do not provide the information required to assess the integrity of ecological systems in a systematic way across regions.

Recognizing this information gap, much attention has recently been focused on the development of concise, understandable, yet accurate "environmental report cards" that summarize the condition of ecological systems. The Environmental Protection Agency has an important role to play in developing the missing information on the condition of the nation's ecosystems for use in such reports. Better information about ecological condition also is a prerequisite for better decision-making within the Agency, on issues ranging from the development of biocriteria to the formulation of research strategies. In addition, the Agency has mandates — as part of the Government Performance and Results Act of 1993, for example — to report more effectively on the state of the nation's environment and the improvements resulting from Agency programs.

To accomplish these tasks, the Agency would benefit from development of a systematic framework for assessing and reporting on ecological condition. The framework would: help assure that the required information is measured systematically by the Agency's programs; provide a template for assembling information across Agency programs and from other agencies; and provide an organizing tool for synthesizing large numbers of indicators into a scientifically defensible, yet understandable, report on ecological condition.

The purpose of this report is to provide the Agency with a sample framework that may serve as a guide for designing a system to assess, and then report on, ecological condition at a local, regional, or national scale. The sample framework is intended as an organizing tool that may help the Agency decide what ecological attributes to measure and how to aggregate those measurements into an understandable picture of ecological integrity.

Environmental reporting usually draws upon a range of measures, from those that capture agency activities to those that provide information about ecological integrity or human health. In addition, reports can focus on economic benefits derived from ecosystems (such as flows of goods and services), or on the condition of human health or ecological resources irrespective of whether quantifiable economic benefits are produced. In this report, we focus exclusively on condition measures related to ecological integrity or because these are a critical — and largely missing — link in the information base upon which environmental reporting can be built.

REPORTING ARCHITECTURE

In order to foster consistent and comprehensive assessment and reporting on the condition of ecological resources, the Panel proposes a framework in which information about generic ecological characteristics can be logically assembled, then synthesized into a few, scientifically defensible categories. Information from these categories can then be excerpted to report on a variety of environmental management goals. This framework for consolidating information can be used as part of a reporting system (Figure ES-1) that contains the following major elements:

Goals and Objectives. Ideally, environmental management programs begin with a process to develop goals and objectives that articulate the desired ecosystem conditions that will result from the program(s). Methods to develop and use goals and objectives for environmental management have been developed extensively elsewhere and are not part of this report.

Essential Ecological Attributes. A set of six Essential Ecological Attributes (EEAs), along with their subdivisions, are presented in Table ES-1 and described in detail in Section 3 of the full report. The EEAs and their component categories and subcategories can be used as a checklist to help design environmental management and assessment programs and as a guide for aggregating and organizing information. The elements of the table and its hierarchical organization are derived from a conceptual model of ecological system pattern and process, and incorporate ecological structure, composition, and function at a variety of scales.

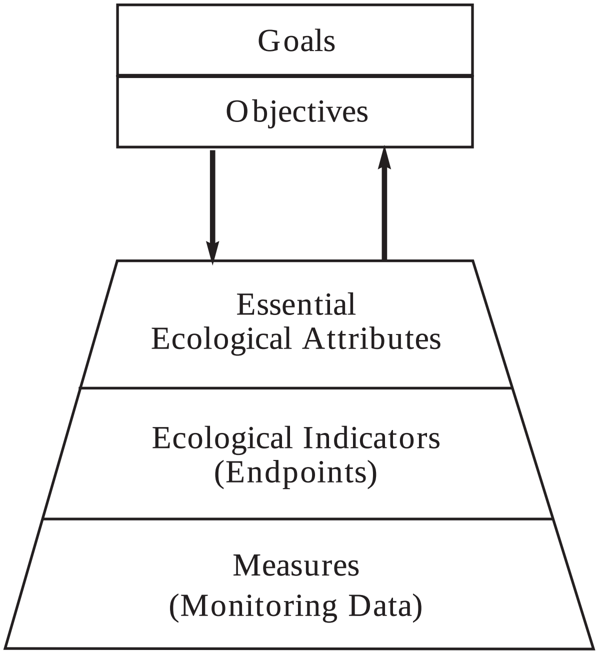


Figure ES-1. Proposed Architecture for Assessing and Reporting on Ecological Condition

Ecological Indicators. Ecological indicators (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of

The Essential Ecological Attributes are independent of specific management objectives.

ecological systems. Multiple indicators may be associated with each subcategory in the EEA hierarchy (see Table ES-2).

Measures. The measures are specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators (or endpoints).

The relationship among these components is relatively straightforward. Measures (monitoring data) are aggregated into ecological indicators. Indicators are aggregated into the subcategories of the hierarchy of EEAs. In theory, therefore, the framework provides a mechanism to display the relationship between monitoring data or indicators and the overarching conclusions that can be drawn about the condition of various important ecological attributes.

Figure ES-1 shows a clear separation between goals and objectives in the upper half and EEAs, indicators, and measures in the lower half, to emphasize that EEAs are a function of the ecological systems of interest and are not derived from the goals and objectives. The EEAs are designed to apply generically — that is, to most aquatic and terrestrial systems at the local, regional, or national scale. The independence of the EEA hierarchy from specific management objectives is what makes it amenable to consistent application across many different regions and types of programs. This independence does not mean that the EEAs and objectives are unrelated, however. The EEAs provide an organized body of information from which one can assess a program's success in meeting any set of objectives relating to ecological condition. In other words, a performance measure related to a specific objective of an environmental program will draw information from a unique subset of the EEAs.

Table ES-1. Essential Ecological Attributes and Reporting Categories

Landscape Condition

- Extent of Ecological System/Habitat Types
- Landscape Composition
- Landscape Pattern and Structure

Biotic Condition

- Ecosystems and Communities
  - Community Extent
  - Community Composition
  - Trophic Structure
  - Community Dynamics
  - Physical Structure
- Species and Populations
  - Population Size
  - Genetic Diversity
  - Population Structure
  - Population Dynamics
  - Habitat Suitability
- Organism Condition
  - Physiological Status
  - Symptoms of Disease or Trauma
  - Signs of Disease

Chemical and Physical Characteristics (Water, Air, Soil, and Sediment)

- Nutrient Concentrations
  - Nitrogen
  - Phosphorus
  - Other Nutrients
- Trace Inorganic and Organic Chemicals
  - Metals
  - Other Trace Elements
  - Organic Compounds
- Other Chemical Parameters
  - pH
  - Dissolved Oxygen
  - Salinity
  - Organic Matter
  - Other
- Physical Parameters

Ecological Processes

- Energy Flow
  - Primary Production
  - Net Ecosystem Production
  - Growth Efficiency
- Material Flow
  - Organic Carbon Cycling
  - Nitrogen and Phosphorus Cycling
  - Other Nutrient Cycling

Hydrology and Geomorphology

- Surface and Groundwater Flows
  - Pattern of Surface Flows
  - Hydrodynamics
  - Pattern of Groundwater Flows
  - Salinity Patterns
  - Water Storage
- Dynamic Structural Characteristics
  - Channel/Shoreline Morphology, Complexity
  - Distribution/Extent of Connected Floodplain
  - Aquatic Physical Habitat Complexity
- Sediment and Material Transport
  - Sediment Supply/Movement
  - Particle Size Distribution Patterns
  - Other Material Flux

Natural Disturbance Regimes

- Frequency
- Intensity
- Extent
- Duration

ESSENTIAL ECOLOGICAL ATTRIBUTES

The EEAs — Landscape Condition, Biotic Condition, Chemical and Physical Characteristics, Ecological Processes, Hydrology and Geomorphology, and Natural Disturbance Regimes — divide up the universe of information that describes the state of an ecological system in a logical manner that is solidly grounded in current scientific understanding. The EEAs include three ecological attributes that are primarily "patterns" (Landscape Condition, Biotic Condition, and Chemical/Physical Characteristics) and three that are primarily "processes"(Hydrology/ Geomorphology, Ecological Processes, and Natural Disturbance). Describing ecological systems in terms of pattern and process has a long history in ecological science and has been a useful construct for many years. In a nutshell, the processes create and maintain patterns, which consist of the elements in the system and the way they are arranged; these patterns in turn affect how processes are expressed (e.g., a riparian forest's effect on river flow and velocity).

In order to subdivide pattern and process into EEAs, the Panel elected to highlight ecological characteristics that often are overlooked by the Agency and by members of the public (such as landscape structure, natural disturbance, and ecological processes). For ease of use, the Panel grouped characteristics that generally are measured together. The EEAs and their component categories and subcategories are summarized in Table ES-2, and described in detail in the full report.

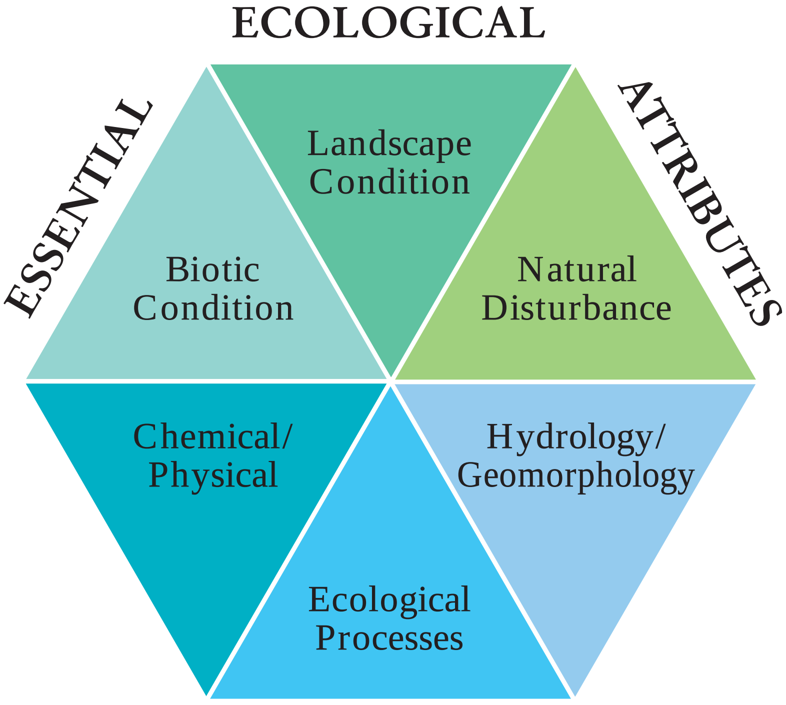


Figure ES-2.

Table ES-2. Summary of Essential Ecological Attribute Categories and Subcategories, With Example Indicators and Measures

LANDSCAPE CONDITION		
Category	**Subcategory**	**Example Indicators and Measures**
Extent of Each Ecological System/Habitat Type		e.g., area; perimeter-to-area ratio; core area; elongation
Landscape Composition		e.g., number of habitat types; number of patches of each habitat; size of large patch; presence/absence of native plant communities; measures of topographic relief, slope, and aspect
Landscape Pattern/Structure		e.g., dominance; contagion; fractal dimension; distance between patches; longitudinal and lateral connectivity; juxtaposition of patch types or serial stages; width of habitat adjacent to wetlands
BIOTIC CONDITION		
Ecosystems and Communities	Community Extent	e.g., extent of native ecological communities; extent of successional states
	Community Composition	e.g., species inventory; total species diversity; native species diversity; relative abundance of species; % non-native species; presence/abundance of focal or special interest species (e.g., commonness/rarity); species/taxa richness; number of species in a taxonomic group (e.g., fishes); evenness/dominance across species or taxa
	Trophic Structure	e.g., food web complexity; presence/absence of top predators or dominant herbivores; functional feeding groups or guilds
	Community Dynamics	e.g., predation rate; succession; pollination rate; herbivory; seed dispersal
	Physical Structure	e.g., vertical stand structure (stratification or layering in forest communities); tree canopy height; presence of snags in forest systems; life form composition of plant communities; successional state
Species and Populations	Population Size	e.g., number of individuals in the population; size of breeding population; population distribution; number of individuals per habitat area (density)
	Genetic Diversity	e.g., degree of heterozygosity within a population; presence of specific genetic stocks within or among populations
	Population Structure	e.g., population age structure
	Population Dynamics	e.g., birth and death rates; reproductive or recruitment rates; dispersal and other movements
	Habitat Suitability (Focal Species)	measures of habitat attributes important to focal species
Organism Condition	Physiological Status	e.g., glycogen stores and blood chemistry for animals; carbohydrate stores, nutrients, and polyamines for plants; hormone levels; enzyme levels
	Symptoms of Disease or Trauma	e.g., gross morphology (size, weight, limb structure); behavior and responsiveness; sores, lesions and tumors; defoliation
	Signs of Disease	e.g., presence of parasites or pathogens (e.g., nematodes in fish); tissue burdens of xenobiotic chemicals
CHEMICAL AND PHYSICAL CHARACTERISTICS (WATER, AIR, SOIL, SEDIMENT)		
Nutrient Concentrations	Nitrogen	e.g., concentrations of total N; NH_4, NO_3; organic N, NOx; C/N ratio for forest floor
	Phosphorus	e.g., concentrations of total P; ortho-P; particulate P; organic P
	Other Nutrients	e.g., concentrations of calcium, potassium, and silicon
Trace Inorganic and Organic Chemicals	Metals	e.g., copper and zinc in sediments and suspended particulates
	Other Trace Elements	e.g., concentrations of selenium in waters, soils, and sediments
	Organic Compounds	e.g., methylmercury, selenomethionine
Other Chemical Parameters	pH	e.g., pH in surface waters and soil
	Dissolved Oxygen/ Redox Potential	e.g., dissolved oxygen in streams; soil redox potential
	Salinity	e.g., conductivity
	Organic Matter	e.g., soil organic matter; pore water organic matter concentrations
	Other	e.g., buffering capacity; cation exchange capacity
Physical Parameters	Soil/Sediment	e.g., temperature; texture; porosity; soil bulk density; profile morphology; mineralogy; water retention
	Air/Water	e.g., temperature; wind velocity; relative humidity; UV-B PAR; concentrations of particulates; turbidity

ECOLOGICAL PROCESSES		
Energy Flow	Primary Production	e.g., production capacity (total chlorophyll per unit area); net primary production (plant production per unit area per year); tree growth or crop production (terrestrial systems); trophic status (lakes); 14-CO_2 fixation rate (aquatic systems)
	Net Ecosystem Production	e.g., net ecosystem organic carbon storage (forests); diel changes in O_2 and CO_2 fluxes (aquatic systems); CO_2 flux from all ecosystems
	Growth Efficiency	e.g., comparison of primary production with net ecosystem production; transfer of carbon through the food web
Material Flow	Organic Carbon Cycling	e.g., input/output budgets (source identification-stable C isotopes); internal cycling measures (food web structure; rate and efficiency of microbial decomposition; carbon storage); organic matter quality and character
	N and P Cycling	e.g., input/output budgets (source identification, landscape runoff or yield); internal recycling (N_2-fixation capacity; soil/sediment nutrient assimilation capacity; identification of growth-limiting factors; identification of dominant pathways)
	Other Nutrient Cycling (e.g., K, S, Si, Fe)	e.g., input/output budgets (source identification, landscape yield); internal recycling (identification of growth-limiting factors; storage capacity; identification of key microbial terminal electron acceptors)
HYDROLOGY AND GEOMORPHOLOGY		
Surface and Groundwater Flows	Pattern of Surface Flows (rivers, lakes, wetlands, and estuaries)	e.g., flow magnitude and variability, including frequency, duration, timing, and rate of change; water level fluctuations in wetlands and lakes
	Hydrodynamics	e.g., water movement; vertical and horizontal mixing; stratification; hydraulic residence time; replacement time
	Pattern of Groundwater Flows	e.g., groundwater accretion to surface waters; within-groundwater flow rates and direction; net recharge or withdrawals; depth to groundwater
	Spatial and Temporal Salinity Patterns (estuaries and wetlands)	e.g., horizontal (surface) salinity gradients; depth of pycnocline; salt wedge
	Water Storage	e.g., water level fluctuations for lakes and wetlands; aquifer capacity
Dynamic Structural Characteristics	Channel Morphology; Shoreline Characteristics; Channel Complexity	e.g., mean width of meander corridor or alternative measure of the length of river allowed to migrate; stream braidedness; presence of off-channel pools (rivers); linear distance of marsh channels per unit marsh area; lithology; length of natural shoreline
	Distribution and Extent of Connected Floodplain (rivers)	e.g., distribution of plants that are tolerant to flooding; presence of floodplain spawning fish; area flooded by 2-year and 10-year floods
	Aquatic Physical Habitat Complexity	e.g., pool-to-riffle ratio (rivers); aquatic shaded riparian habitat (rivers and lakes); presence of large woody debris (rivers and lakes)
Sediment and Material Transport	Sediment Supply and Movement	e.g., sediment deposition, sediment residence time and flushing
	Particle Size Distribution Patterns	e.g., distribution patterns of different grain/particle sizes in aquatic or coastal environments
	Other Material Flux	e.g., transport of large woody debris in rivers
NATURAL DISTURBANCE REGIMES		
Example 1: Fire Regime in a forest	Frequency	e.g., recurrence interval for fires
	Intensity	e.g., occurrence of low intensity (forest litter fire) to high intensity (crown fire) fires
	Extent	e.g., spatial extent in hectares
	Duration	e.g., length of fire events (from hours to weeks)
Example 2: Flood Regime	Frequency	e.g., recurrence interval of extreme flood events
	Intensity	e.g., number of standard deviations from 30-year mean
	Extent	e.g., number of stream orders (and largest order) affected
	Duration	e.g., number of days, percent of water year (October 1- September 30)
Example 3: Insect Infestation	Frequency	e.g., recurrence interval for insect infestation outbreaks
	Intensity	e.g., density (number per area) of insect pests in an area
	Extent	e.g., spatial extent of infested area
	Duration	e.g., length of infestation outbreak

The Clinch River in Tennessee, seen as part of a landscape that includes forest, riparian, and open field habitats. Photo by V. Dale.

Managing entire landscapes, not just individual habitat types, is important for maintaining native biodiversity.

Landscape Condition

A landscape is an area composed of a mosaic of interacting ecosystems, or habitat patches. Habitat condition may reflect both abiotic features (e.g., elevation, proximity to water) and biotic features (e.g., dominant species, presence of predators). A change in the size and number of natural habitat patches, or a change in connectivity between habitat patches, affects the probability of local extinction and loss of diversity of native species and can affect regional species persistence. Patch heterogeneity also affects both biotic and abiotic landscape processes (e.g., extent of insect infestation, surface water flows). Thus, there is empirical justification for managing entire landscapes, not just individual habitat types, in order to insure that native plant and animal diversity is maintained. The Panel recommends that landscape indicators be reported in the following three categories:

Extent. The areal extent of each habitat type within a landscape is important because a decrease in the total area of habitat available often is correlated with species decline. Extent may be reported for broad land cover classes, for finer subunits, or both.

Landscape Composition. Landscape composition can be measured by several metrics, including the number of landcover/habitat types, the number of patches of each habitat, and size of the largest patch (because populations are unlikely to persist in landscapes where the largest patch is smaller than that species' home range).

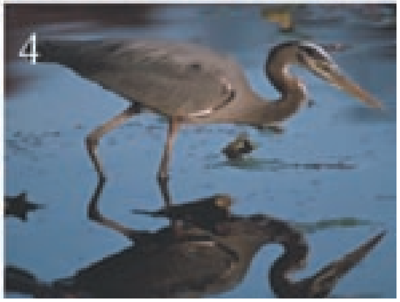
Landscape Pattern/Structure. The spatial pattern of habitat affects population viability of native species. Recent advances in remote sensing and geographic information systems (GIS) allow indices of pattern to be applied over large areas.

Biotic Condition

For this reporting framework, the Panel defines biotic condition to include structural and compositional aspects of the biota below the landscape level (i.e., for ecosystems or communities, species/populations, individual organisms, and genes). Within these biological levels of organization, measures of composition (e.g., the presence or absence of important elements, and diversity) and structural elements that relate directly to functional integrity (such as trophic status or structural diversity within habitats) are considered.

Ecosystem or Community Measures. An ecological community is the assemblage of species that inhabit an area and are tied together by similar ecological processes (e.g., fire, hydrology), underlying environmental features (e.g., soils, geology) or environmental gradients (e.g., elevation, temperature), and form a cohesive, distinguishable unit. In this framework, community measures are divided into subcategories that are consistent with the concept of "biotic integrity" as defined by Agency guidance on biological assessment and biological criteria.

Species or Population Level Measures. Measures of the condition or viability of populations of species in an area are important indicators, yet monitoring the status of all species is impossible from a practical standpoint. To address this problem, a higher taxonomic level can be used, or a subset of species called focal species can be monitored. Focal species are selected because they exert a disproportionately important influence on ecosystem condition or provide information about the ability of the system to support other species. In addition, some species (such as endangered, rare, sensitive,



1.) Mixed tropical forest stand in Central Mexico. Photo by G. Keith Douce, University of Georgia. Image 1673020. http://www.forestryimages.org

2.) Leaf blister on poplar leaves is a symptom of foliage disease caused by the fungi *Taphrina populina*. Photo by T.D. Leninger, USDA Forest Service. Image 3046084. http://www.forestryimages.org/

3.) Bumble bees and other natural pollinators play a critical role in an ecological community. Photo by David L. Green, Copyright (2001), used with permission. http://www.pollinator.com/gallery/bumblebee_azalea.htm

4.) Heron feeding in a salt marsh. Photo by S.C. Delaney, U.S. EPA.

Focal species provide information on the condition of ecological communities.

and game species) require attention because they relate to biodiversity or because they are of direct interest to society for other reasons.

Individual Organism Measures. Whereas the preceding categories of biotic condition are concerned largely with system, community, or population level measures, there are instances when the health of particular individuals (e.g., for focal species or for species imperiled or vulnerable to extinction or extirpation from an area) may be of interest. In addition, the health of individuals may presage an effect on a population or related ecological process (e.g., the presence of life-threatening birth defects in an animal population, or symptoms of disease in a forest).

Chemical and Physical Characteristics (of Air, Water, Soil, and Sediment)

The characteristics included here are measures of chemical substances that are naturally present in the environment and physical parameters (such as temperature and soil texture). These environmental attributes have received substantial public attention and monitoring because they are the subject of pollution control laws (e.g., the Clean Air Act, the Clean Water Act). The categories listed below may be reported separately for air, for water, and so forth. Alternatively, categories can be used to display integrated information from all environmental compartments (air, water, soil, and sediment) at once.

Nutrient concentrations. Nutrients are those elements required for growth of autotrophic organisms, whose ability to produce organic matter from inorganic constituents forms the ultimate base of food webs. Concentrations of nutrients, including phosphorus, nitrogen, potassium, and micronutrients (e.g., copper, zinc, and selenium) may be limiting if available in too small a quantity or may lead to undesirable consequences if present in too great a quantity.

Trace inorganic and organic chemicals. Baseline information about concentrations of metals and organic chemicals (whether or not their concentrations are altered by pollutant discharges) provides a foundation for assessing their ecological significance.

Other chemical parameters. Other chemical parameters that should be reported will differ depending on the environmental compartment (water, air, soil, and/or sediment) being assessed. In soils and sediments, for example, measures such as total organic matter, cation exchange capacity, and pH will be important.

Physical parameters. Physical measures, such as air and water temperature, wind velocity, water turbidity, and soil bulk density, complement the measures of physical habitat contained in other EEAs.

Ecological Processes

For this reporting framework, the Panel defines ecological processes as the metabolic functions of ecosystems — energy flow, elemental cycling, and the production, consumption and decomposition of organic matter. Biotic processes (which are included under biotic condition for convenience) also could be included here. Many of the ecological process indicators are taken from *Ecological Indicators for the Nation*, recently published by the National Research Council (NRC). The Panel stresses, as did NRC, that adequate indicators are not yet available for all of the key attributes of energy and material flows in ecosystems.

Energy Flow. The most basic ecosystem attribute, fundamental to life on earth, is ecosystem productivity, or the ability to capture sunlight and convert it to high energy organic matter (biomass), which then supports the non-photosynthetic trophic levels, including grazers, predators, and decomposers. The balance among production, consumption, and decomposition defines the efficiency of an ecosystem and its ability to provide the goods and services upon which society depends.

Material Flow. Biogeochemical cycles that are key to ecosystem function include cycling of organic matter and inorganic nutrients (e.g., nitrogen, phosphorous, and micronutrients such as selenium and zinc). Material and energy flow are linked processes and many indicators provide information on both.

Water lilies in the Florida Everglades. Photo by C. Gilmour.

Hydrology and Geomorphology

The hydrology and geomorphology of ecological systems reflect the dynamic interplay of water flow and landforms. In river systems, for example, water flow patterns and the physical interaction among a river, its riverbed, and the surrounding land determine whether a naturally diverse array of habitats and native species are maintained. Sediment transport partially determines which habitats occur where (both above the water and below it). The dynamic structural characteristics — the biotic and abiotic components of the water-related habitats — are created and maintained by both water and sediment flows.

The quantity and variability of water flows control the creation and succession of many habitats.

1.) Channel complexity in marshes and river floodplains provides a variety of habitats for fish and wildlife. Photo by S.C. Delaney, U.S. EPA.

2.) Large woody debris and gravel bars provide physical structure and habitat diversity along the Dungeness River in Washington State. Photo by F. Taub.

3.) A meandering stream with riparian forest at Fort Benning, GA provides habitat complexity, with a variety of water depths, flow velocities, and depositional environments. Photo by V. Dale.

Water Flow. Surface and groundwater flows determine which habitats are wet or dry and when, and water flows transport nutrients, salts, contaminants, and sediments. It is less widely recognized, however, that the variability of water flows (in addition to their timing and magnitude) exerts a controlling influence on the creation and succession of habitat conditions.

Dynamic structural characteristics. Structural characteristics in streambeds (or lakebeds or bottom terrain of estuaries) and banks (or shoreline) are maintained by water flows and sediment movement. Accordingly, measures of dynamic structural characteristics reflect the integrity of these processes and provide direct information about the quality and diversity of habitats. Characteristics included in this category include channel morphology and shoreline characteristics, channel complexity, distribution and extent of connected floodplain, and aquatic physical habitat complexity.

Sediment and other material transport. A wide variety of underwater, riparian, and wetland habitats are maintained by the pattern of sediment and debris movement. Native species have adapted accordingly; for example, many anadromous fish require clean gravels for spawning, and invertebrates choose particular particle sizes for attachment or burrowing.

Natural Disturbance Regimes

All ecological systems are dynamic, due in part to discrete and recurrent disturbances that may be physical, chemical, or biological in nature. Examples of natural disturbances include wind and ice storms, wildfires, floods, drought, insect outbreaks, microbial or disease epidemics, invasions of nonnative species, volcanic eruptions, earthquakes and avalanches. The frequency, intensity, extent, and duration of the events taken together are referred to as the "disturbance regime." Each of the disturbance regimes that is relevant to the ecological system should be included in the assessment.

1.) Wildfire in forested systems contributes to the maintenance of species diversity by allowing for the growth of understory grasses and forbs and release of seeds from some cone-bearing trees. Photo by W. Ostrofsky, University of Maine.

2.) Ice storm damage to trees contributes to downed woody debris on the forest floor and the formation of debris dams in adjacent streams. Photo by Billy Humphries, Forest Resource Consultants, Inc. Image 1450036. http://www.forestryimages.org.

THE ROLE OF STRESSOR INDICATORS

Stressor indicators provide information on underlying causes of compromised ecological condition.

In practice, reports about ecological condition often indiscriminately mix condition indicators with indicators of stressors such as pollution. The framework presented here distinguishes between ecological condition indicators and indicators of anthropogenic stressors, and the EEAs relate only to condition. This approach is consistent with that of the National Research Council (2000) and The Heinz Center (1999).

Other environmental reporting schemes incorporate both condition and stressor indicators, but are careful to distinguish the two. The internationally recognized "Pressure-State-Response" model of environmental indicators developed by the Organisation for Economic Cooperation and Development (OECD, 1998) distinguishes pressures (i.e., stressors) from state (i.e., condition) variables. The ecological assessment scheme for the Great Lakes (Environment Canada and U.S. EPA, 1999) follows the OECD format.

Distinguishing between condition indicators and stressor indicators is important because the correlation is not one-to-one: many stressors affect more than one condition attribute, and many condition attributes are affected by more than one stressor (Figure ES-3). Assessment of ecological condition, therefore, shows the effects of multiple stressors acting at once and can highlight unforeseen effects. Assessing the full array of condition indicators in parallel with an array of stressor indicators also aids elucidation of causal mechanisms underlying compromised ecosystem conditions. A third reason for distinguishing between condition and stressor indicators is to avoid relying exclusively on available data — which generally focuses on anthropogenic stressors targeted by regulations — and thereby overlooking important characteristics relating to ecological condition (such as habitat changes or changes in water flow patterns). The full array of condition information can help the Agency focus its efforts on the most significant problems, rather than those about which the most data have been collected.

In short, even when the goal of an environmental program relates to the management of stressors, it may well be necessary to assess both ecological condition and stressors, and then assess the relationship between the two. The SAB framework can be adapted to incorporate parallel information about stressors for this purpose (see Section 4 of the full report). In addition, the array of ecological attributes shown in Table ES-1 can be used as a checklist to identify components that should be addressed in stressor-focused ecological risk assessments.

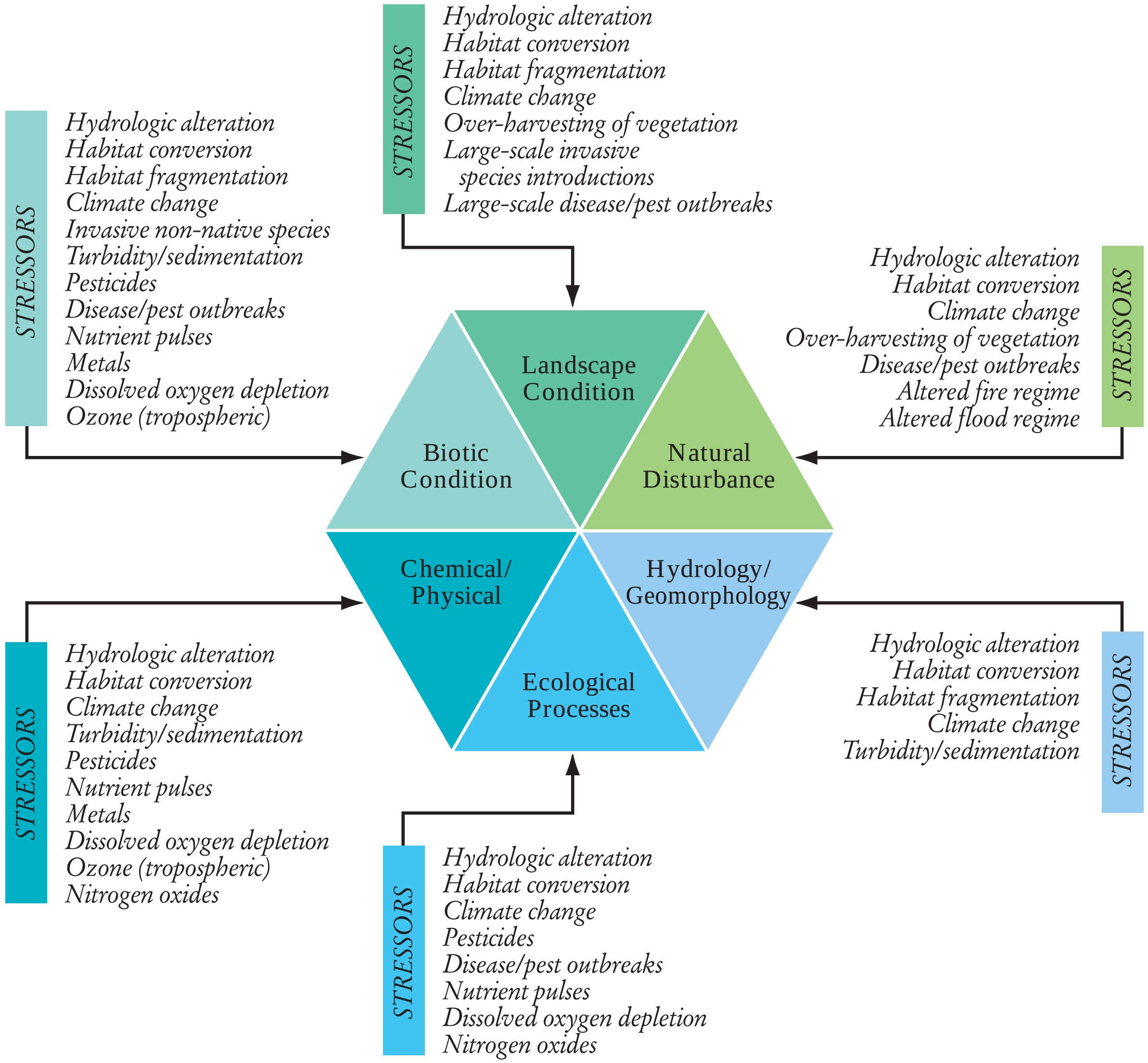


Figure ES-3. Ecological stressors affect multiple aspects of condition.

APPLYING THE FRAMEWORK

Designing an Ecological Condition Assessment

One purpose of the EEA hierarchy (Table ES-1) is to provide organizational structure for the process of selecting ecological system characteristics that will be assessed. Once the purpose and scope of the assessment have been determined (as described in Section 5 of the full report), the EEA list can be applied. The Panel recommends beginning with a rebuttable presumption that all of the entries in Table ES-1 will be included. A "thought experiment" can then be conducted to eliminate the subcategories and categories that are not relevant to the assessment. When resources are limiting, the Panel generally recommends limiting the number of subcategories for which data are collected, rather than eliminating an entire category. Similarly, it may be preferable to limit the number of categories assessed rather than eliminating an entire EEA.

Following the initial selection of EEA categories and subcategories, a series of checks should be undertaken to assure that the selections accomplish the intended goals and are scientifically defensible. For example, the list should be analyzed to assure that its components are sufficient to address any goals and objectives that have been developed for management of the ecological system. Similarly, components of the list should be sufficient to address questions of known public interest (such as the preservation of economically valuable species or the sustainability of patches of old-growth forest). If the list falls short, then additional indicators may be added. The final product of the design process should not only describe the assessment and reporting scheme, but also transparently record the decision tree and professional judgments used to develop it.

Creating a Report

Effective reporting on ecological condition requires policy judgments and scientific understanding (to determine what to report), and it requires communications expertise (to determine how to report it). Here, the Panel addresses only the scientific issues.

The SAB framework provides a scientifically derived scheme for combining hundreds of different indicators into a few ecologically related categories for reporting. Using Table 1 as a guide, the information from an array of indicators can be grouped into a single subcategory and — if desired — collapsed into a single quantitative or qualitative entry. The information within subcategories can then be aggregated into a single category, and so forth. The discovery that some categories lack data also is important information for both decision-makers and the public.

Depending on the level of interest and expertise of the audience, reports can be issued at the level of individual indicators, subcategories, categories, EEAs, or the ecological system as a whole. Many reports combine several levels of reporting. If the objective of the report is to provide information on ecosystem integrity and sustainability, then the EEAs can be used as reporting units (i.e., a “score” or qualitative assessment would be presented for each EEA). The concepts behind the EEAs are fairly straightforward; for non-technical audiences, the presentation would benefit from conversion into lay language. For example, hydrology and geomorphology might become a description of “water flows and riverbanks” for a river basin report.

Alternatively, the information that has been aggregated into EEAs and categories can be extracted in order to report on a particular management objective. For example, an objective such as “protect functional habitat types throughout the watershed” might use the extent category of Landscape Condition to report directly on the amount of each habitat currently in existence. In addition, a consolidated “indicator” that incorporates the Hydrology/Geomorphology, Disturbance, Ecological Processes, and Landscape Condition EEAs might be used to report whether these habitats are functional and likely to be maintained into the future.

The process of aggregating information from multiple indicators into a single entry for reporting — even following the template in Table ES-1 — involves nontrivial scientific judgments. An expansive scientific literature is available to determine appropriate methods for creating indices and aggregating measures into endpoints, endpoints into categories, and so forth.

Interpreting Indicator Values

To make the proposed reporting framework operational, reference conditions should be defined against which measured values for indicators can be compared. The reference conditions are helpful for interpreting results and are required in order to determine how results can be normalized (qualitatively or quantitatively) for aggregation. This normalization procedure allows various indicators to be collapsed into one result, and it allows results from different regions to be compared. The Panel recommends that the Agency support current efforts to develop reference conditions for this purpose.

EXAMPLE APPLICATIONS OF THE FRAMEWORK

To illustrate the proposed framework's application to programs at different geographic scales and with different objectives, as well as to check the completeness of the framework, the Panel selected four environmental reporting programs as case examples: an Office of Research and Development program designed to assess condition of ecological systems; a USDA Forest Service program designed to assess forest condition nationwide; the Office of Water's Index of Watershed Indicators (IWI), designed to convey information to the public about watershed condition; and a joint EPA-state reporting program designed to track progress meeting environmental goals. The Panel, along with representatives of the programs, reviewed these case studies to determine whether components should be added to the framework, whether the framework provided a useful checklist for the program, and whether the framework provided a reasonable way to organize and report on the program's indicators. The Panel appreciates the assistance and cooperation of the programs' representatives for these road tests.

The Office of Research and Development's **Environmental Monitoring and Assessment Program (EMAP)** includes a pilot project that will assess aquatic resources within streams, landscapes, and estuaries in a twelve-state region of the western U.S. Comparison of the EMAP-West indicators with the SAB framework indicates that all of the EMAP-West components can be nested within the SAB framework, but that several of the categories included in the SAB framework are omitted from EMAP-West. Landscape condition, disturbance regimes (i.e., fire, flood, drought, volcanic activity), and ecological processes were notably lacking in coverage. These omissions may make it more difficult for EMAP-West to accomplish its intended purpose. In this example, therefore, it appears that use of the EEA hierarchy as a checklist provides valuable insight that might be incorporated as the program evolves. In addition, the EEA hierarchy could be employed to organize EMAP-West data into data systems for local groups, thereby creating a structure into which information from other monitoring programs could be integrated.

The **USDA's Forest Health Monitoring (FHM) Program** assesses the condition and health of both public and private forests nationwide. The program focuses on sustainability of forest system integrity and the effects of stressors thereon. Despite its initial focus on stressors, however, the FHM metrics fit within the proposed EEA categories. Conversely, the FHM measures provide fairly complete coverage of the EEA hierarchy with the exception of hydrology/geomorphology.

Using the SAB reporting framework to organize and describe the FHM indicators, therefore, helps reinforce the value of both because they are so consistent in content. Moreover, the EEA hierarchy provides an organization scheme that could be used to combine FHM information with monitoring data from other agencies because it can be adapted for use in different ecosystem types at a variety of scales.

The **Index of Watershed Indicators (IWI)** displays information on the EPA web site about the "condition and vulnerability" of watersheds. The Panel found that the IWI indicators are predominantly stressor indicators and that the condition indicators that are included are notably lacking in coverage, with the exception of the traditional Agency territory of physical and chemical parameters. Although this is understandable given the Agency's history, it is not the overview of watershed condition that the web site advertises nor what the public expects to find. On the other hand, there is no reason that additional parameters cannot be added in the future in order to provide a more balanced picture of watershed condition. The SAB framework would provide a method to choose additional indicators, and it would provide a scientific and logical justification for the IWI's composite indices and maps.

The **National Environmental Performance Partnership System (NEPPS)** uses "core performance measures" to track the states' progress towards meeting environmental goals. The current array of ecosystem-related core performance measures tracks only chemical and physical characteristics and a small subset of biotic condition. Examination of a sample state NEPPS report, however, shows far more complete coverage than the generic core performance measures imply. The EEA hierarchy can be used profitably by the NEPPS program to determine how ecosystem condition (or a subset such as biotic condition) can be assessed, and it offers a method to organize and consolidate information about a variety of ecosystem types. The reporting categories of the SAB framework appear awkward for the NEPPS core performance measures at the present time, however, because the measures primarily are focused on reporting about changes in pollutant levels resulting from particular legislated mandates. Measures of other attributes — such as landscape condition, biotic condition, and hydrology that are included in the sample state report — could be grouped into EEAs for reporting. This approach might help to convey to the public the ecological significance of the collection of measures.

CONCLUSIONS

The framework presented here provides a valuable tool for assessing the condition of ecological systems. In every example program tested by the Panel, the list of Essential Ecological Attributes and associated subdivisions proved useful. In all cases, use of the EEA hierarchy as a checklist highlighted missing elements — elements representing ecological system characteristics broad enough in scope and importance to affect the achievement of the programs' objectives. Recognizing that resources are always limited and that expanding a program is often infeasible, the EEA checklist provides a method to analyze the tradeoffs inherent in choosing which characteristics to address. The fact that the checklist is organized hierarchically allows the user to determine whether major characteristics (e.g., the entire array of hydrology and geomorphology characteristics) are being eliminated from consideration in favor of a cluster of closely-related attributes (e.g., every subcategory and indicator of biotic condition at the community level).

In most cases, the elements that were omitted by Agency programs were those outside the realm of biotic condition and chemical and physical characteristics. This pattern has been noted by the SAB in the past and it is an understandable outgrowth of the issues targeted by the Agency's legal mandates. A more complete look at ecological characteristics is key, however, to allow the Agency to: analyze correctly the causes of environmental degradation; effectively target corrective actions; and help address environmental problems across large geographic areas such as watersheds.

The framework can be applied to a variety of aquatic and terrestrial systems at local, regional, and national scales.

The programs that were analyzed included both aquatic and terrestrial systems at a variety of geographic scales. For all of these examples, the SAB framework and EEA hierarchy provided a reasonable way to organize a broad array of indicators. After each example was tested, the Panel was able to fine-tune the organizational scheme by grouping characteristics into slightly different bundles at the subcategory level. Presumably this fine-tuning will still be necessary as the SAB framework is applied to additional programs. In no case, however, did the Panel find that important elements of condition were missing from the framework.

The Essential Ecological Attributes and their subdivisions provide a logical method for grouping ecologically related elements across system types (such as forests, rangelands, and aquatic systems) and/or across programs that have different legal mandates.

This feature can be used when the Agency addresses problems that span different "media" (i.e., water, air and land) in order to provide environmental protection for watersheds and other geographic units. It also can be used as a unifying framework on which to map various types of ecological assessment activities within the Agency. There is clear justification for a variety of different programs with different purposes to exist within the Agency, among other federal agencies, and in the private sector for the purpose of assessing ecological condition. This diversity brings strength and depth to our understanding. It does not, by itself, insure that efficiencies among programs are realized, that deficiencies in programs are addressed, or that the information from one assessment is used to enhance the understanding gained from other studies. The SAB framework provides a template that potentially could be used to foster greater integration, a higher quality of ecological assessment, and increased efficiency among Agency programs. It also could be used to assist the Agency to become a locus for integrating information from different government agencies.

The Essential Ecological Attributes and their subdivisions can be used to organize and consolidate a large number of indicators into a few, conceptually clear categories for reporting.

One major purpose of this framework and EEA list (Table ES-1) is to help avoid common reporting problems. For example, report authors often discover that there are numerous relevant ecological indicators, yet there is little guidance available about how they should be distilled into a few scientifically credible indicators for the public. Moreover, most of the easily accessible information (e.g., water quality data regarding chemical contaminants) may be related to past problems and reflects only part of the information required to predict future problems or manage the ecosystem. The framework presented here can help avoid these problems by providing a roadmap for grouping monitoring data and indicators into scientifically defensible categories that directly relate to important characteristics of ecological condition. These categories are straightforward, and they can therefore be explained to decision-makers, legislators, and the public. The language used by the Panel would not, however, be suitable for this purpose. Translation into lay language would be required.

This framework can provide the foundation for reporting on a variety of independently-derived goals and objectives, including those mandated by legislation or public policy.

When the purpose of a report is to address questions of particular interest to the public or address goals embodied in legislation or regulation, the SAB framework provides a way to organize information that can then be extracted for reporting. For example, a "report card" entry on the health of native habitats, plants, and animals would draw from the information aggregated into the landscape condition and biotic condition EEAs. A companion report card entry on the ability of the ecosystem to sustain healthy plants and animals into the future would add information from each of the remaining EEAs. In some cases, however, the SAB framework provides the requisite information but does not work well for organizing indicators into a report. One example would be a regional water quality report for which data will be drawn from monitoring programs designed specifically for that purpose. In this example, the SAB framework is better used as an analytical tool than a report outline.

In sum, the Panel finds that the proposed framework accomplishes its intended purpose. The framework provides a checklist that can help identify the ecological attributes that are important to assess in order to evaluate the health or integrity of ecological systems. It also provides an organizational scheme for assembling hundreds of individual parameters into a few understandable attributes. Ecological systems are complex, and it has proved extremely difficult to answer the holistic questions that people ask about them — "How healthy is my watershed? Will native species be here for my children and grandchildren to enjoy?" With this report, we provide a way to integrate scientific data into the information necessary to answer these questions, and ultimately to foster improved management and protection of ecological systems.

REFERENCES CITED

Environment Canada and U.S. Environmental Protection Agency. 1999. State of the Great Lakes. EPA 905-R-99-008. EPA Great Lakes National Program Office, Chicago, IL. www.epa.gov/glnpo/solec/.

National Research Council. 2000. Ecological Indicators for the Nation. Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, Board on Environmental Studies and Toxicology [and] Water Science and Technology Board. National Academy Press, Washington, DC.

Organisation for Economic Cooperation and Development (OECD). 1998. Towards Sustainable Development: Environmental Indicators.

The Heinz Center. 1999. Designing a Report on the State of the Nation's Ecosystems: Selected Measurements for Croplands, Forests and Coasts and Oceans. The H. John Heinz III Center, Washington, DC. www.us-ecosystems.org.

The full report to this Executive Summary, *A Framework for Assessing and Reporting on Ecological Condition: An SAB Report* (EPA-SAB-EPEC-02-009) is available on the EPA Science Advisory Board website at www.epa.gov/sab or by contacting:

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