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A Framework For Assessing and Reporting on Ecological Condition: An SAB Report

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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

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

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

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OFFICE OF
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SCIENCE ADVISORY BOARD

EPA-SAB-EPEC-02-009

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,

/Signed/

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

/Signed/

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

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Science Advisory Board
Ecological Processes and Effects Committee

Ecological Reporting Panel

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EXECUTIVE SUMMARY

INTRODUCTION

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 condition 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:

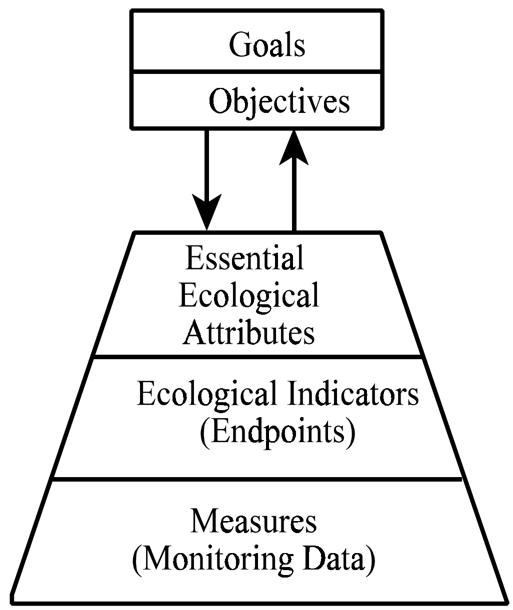

Figure ES-1. Proposed Architecture for Assessing and Reporting on Ecological Condition.

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. 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.

Ecological Indicators. Ecological indicators (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems. Multiple indicators may be associated with each subcategory in the EEA hierarchy (see Table ES-2).

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

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  - Growth Efficiency
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  - Nitrogen and Phosphorus Cycling
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  - Hydrodynamics
  - Pattern of Groundwater Flows
  - Salinity Patterns
  - Water Storage
- Dynamic Structural Characteristics
  - Channel/Shoreline Morphology, Complexity
  - Extent/Distribution 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

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 <u>any</u> 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.

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 below and in Table ES-2, and described in detail in Section 3.

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 largest 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 seral 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

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, 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. 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.

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.

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.

THE ROLE OF STRESSOR INDICATORS

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. 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). 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.

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, 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 ES-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.

SUMMARY

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.

1. THE NATIONWIDE FOCUS ON BETTER ENVIRONMENTAL REPORTING

Virtually every comprehensive study on national environmental protection has called for more coherent and comprehensive information on the state of our environment.

-- William Clark, Thomas Jorling, William Merrell in Designing a Report on the State of the Nation's Ecosystems (The Heinz Center, 1999)

Decision makers and the public need accurate information on ecological conditions and changes for three major reasons. First, a long-term record of conditions is needed as a reference to evaluate current conditions and trends. Second, detailed information on the ecological effects of various human activities and natural events – such as pollution, development, agriculture, climate change, and geomorphological events – is essential for selecting and implementing management options to address problems successfully. Finally, long-term ecological data are needed for society to measure the effectiveness and efficiency of management interventions and to improve them.

-- Gordon Orians, in Ecological Indicators for the Nation (National Research Council, 2000).

1.1 A Systematic Framework for EPA

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 recent publication of *Designing a Report on the State of the Nation's Ecosystems* by The Heinz Center (1999; in press) and *Ecological Indicators for the Nation* by the National Research Council (NRC, 2000) begin to fill this gap. There remains, however, a need to expand upon this foundation in order to create a template for synthesizing information across different types of ecological resources. Moreover, one of the prominent conclusions shared by both The Heinz Center and NRC reports is that much (if not most) of the information required to assess the health of our nation's ecosystems is still unavailable.

In our view, 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 these and other "environmental report cards." 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 (see, e.g., EPA Science Advisory Board, 1994, 1997a, 1998). In addition, the Agency has mandates – as part of the Government Performance and Results Act of 1993 (GPRA), for example – to report more effectively on the state of the nation's environment and the improvements resulting from Agency programs.

Ecological integrity means the presence of structural, compositional, and functional characteristics within the natural range of variability for a particular ecological system.

The inherent complexity of ecological systems, however, makes both the assessment of ecological integrity and the creation of coherent "report cards" challenging tasks. For this reason, the Agency would benefit from development of a systematic framework for assessing and reporting on ecological condition. The framework would: a) help assure that the required information is measured systematically by the Agency's programs; b) provide a template for assembling information across Agency programs and from other agencies; and c) provide an organizing tool for synthesizing large numbers of indicators into a scientifically defensible, yet understandable report on ecological condition (see box).

In order to accomplish these objectives, the reporting framework should be solidly grounded in ecological principles. The reporting categories, as well as the specific measures or indicators within each category, should be related clearly to the characteristics and functions of ecological systems of concern. The reporting categories also should address the fundamental structural and functional attributes of ecological systems. While the framework would incorporate the indicators recommended by the NRC and The Heinz Center, it would encompass a more comprehensive universe of ecological attributes and not be limited to those indicators that are appropriate to assess at the national scale.

The purpose of this report is to provide the Agency with a sample framework for assessing and reporting on ecological condition that:

- **a) identifies ecological attributes that should be measured; and**
- **b) shows how this information may be aggregated into an understandable picture for decision-makers.**

The central feature of this framework is a list of reporting categories that is derived from ecological principles and is organized as a nested hierarchy, much like the organizational chart of an agency or business. This "checklist" specifies ecological attributes that should be considered when assessing ecological condition, and it can be applied to aquatic and terrestrial systems at local, regional, or national scales. It also can be used to identify gaps in current monitoring programs. The list is arranged hierarchically so that the complex array of information can be organized and then presented in a methodical and understandable manner. Finally, the report illustrates how the framework and reporting categories might be applied to selected Agency programs.

Example Applications of the SAB Framework

- As a checklist during the design of an **environmental monitoring** or condition assessment effort (to ensure coverage of the essential ecological attributes of the system being assessed)
- As a checklist during the design of watershed or site-specific **ecological risk assessments** (to ensure that all significant ecological attributes are considered in the conceptual model and in deciding what to protect)
- As a guide for **public reporting and education** on ecological condition (so that environmental indicators are assembled in coherent and meaningful ways to tell a story)
- To set **research priorities** for indicator development (to fill cells in the hierarchy for which indicators do not currently exist)
- To set **data collection priorities** where indicators have been developed (to fill data gaps that hinder environmental decision-making)
- To **integrate environmental information from multiple sources** (to optimize expenditures for monitoring and to provide a more comprehensive assessment of the condition of ecological systems)
- To **assess progress towards environmental goals** at the national, regional, or watershed levels
- To **evaluate the collective performance** of environmental protection and management programs in a geographic area or for an ecological resource type

1.2 Terminology: Types of Environmental Measures

Environmental reporting usually draws upon a range of measures, from those measures that capture programmatic activities to those that portray changes in human populations or the environment. For purposes of this report, we have adopted the definitions in a previous SAB

> In a recent report, *Toward Integrated Environmental Decision-Making*, the SAB (2000) recommended that EPA adopt consistent definitions and terminology for performance measures that are relevant to the Agency. For the current report, we have adopted these definitions, although we have renamed "process measures" to "administrative measures" to distinguish between administrative processes and ecological processes.
>
> a) **Administrative Measures** are measures of administrative effort or program actions that are presumed to result in environmental or health improvements (e.g., number of permits issued, number of enforcement cases pursued, number of contaminated sites cleaned up to standards).
>
> b) **Stressor Measures** are measures (levels) of stressors in the environment used to determine attainment or non-attainment of desired reductions in stressor levels; e.g., total emissions of a pollutant, concentrations of particulates in ambient air, levels of dissolved oxygen or turbidity in a stream, and density of roads in a watershed.
>
> c) **Exposure Measures** are measures of the co-occurrence or contact between an individual or population and environmental stressor(s) over a defined time period. The term "exposure" is traditionally associated with chemical stressors (e.g., contaminant levels in food, concentrations of contaminants in tissues, time-activity measures, and total exposure to a contaminant via all routes), whereas the term co-occurrence is often used as a broader term applicable to chemical, physical, and biological stressors.
>
> d) **Effects Measures** are measures of human and/or ecological effects (e.g., asthma rates, deaths from acute poisoning from household products or pesticides, deaths from cancer, acres of wetlands gained or lost, local extinctions of important species). Changes in these effects measures can be used in one of two ways: (1) to assess the impact of an environmental risk reduction program; and/or (2) for **condition assessment**, in which a suite of effects measures are evaluated and reported in combination to characterize the health or condition of an entire population or ecosystem. Condition assessment provides a baseline against which to evaluate the success of broad policies or multiple decisions impacting a population or geographic region.

report (2000) for the various types of performance measures that are relevant to the Agency: administrative, stressor, exposure, and effects measures (see box).

These categories of performance measures comprise a spectrum (Figure 1). At one end, the administrative measures provide important information for managing ongoing environmental programs but provide no direct information about the state of the resource. At the other end of the spectrum, condition measures provide information about ecological integrity or human health. Although they do not generally relate to a single law or government program, these condition measures:

a) inform decision-makers and the public about the condition of various populations or ecological systems;

b) provide the information required to design environmental management programs (e.g., watershed management, pollution controls, pollution prevention activities); and

c) provide information that can be used to evaluate the performance of the suite of environmental management programs affecting the ecosystem or landscape.

			<u>**Environmental Outcomes**</u>
Administrative Measures	**Stressor Measures**	**Exposure Measures**	**Effects/Condition Measures**
activity measures *output measures* *response indicators*	*pressure indicators* *release measures* *emission measures*	*co-occurrence*	*adverse effects* *health outcomes* *state indicators*

Least directly related to Environmental Outcomes → *Most directly related to Environmental Outcomes*

Figure 1. Spectrum of Environmental Performance Measures (Modified from EPA Science Advisory Board, 2000)

Condition measures generally are defined from one of two fundamental perspectives. The first perspective — referred to here as "sustainable flows"— evaluates flows of products such as lumber or fish; or services, such as recreational opportunities or soil conservation. The second perspective — referred to here as "sustainable state"— evaluates ecological health or integrity. Figure 2 illustrates these two approaches for forest ecosystems. The second approach provides an important underpinning for the first, because it captures information about future products; services that are not yet recognized or measured; and characteristics with existence (or passive use) values. The second approach also may provide earlier signals regarding changes in relationships among ecological constituents that affect future productivity, such as might occur as a result of global climate change. In addition to providing information about these utilitarian (anthropocentric) values, assessments of ecological integrity also inform biocentric values. Biocentric values incorporate the inherent worth of ecosystems that is independent of any benefits in the form of product or service flows to human societies (see, e.g., Goulder and Kennedy, 1997 for further discussion).

While there is no "correct" evaluation strategy, it is important to recognize that the world view underlying an assessment and reporting system influences the selection of environmental metrics. In the case of a "sustainable flows" focus, appropriate metrics would measure the rate and sustainability of the product/service flows from the ecological resource to humans. In the

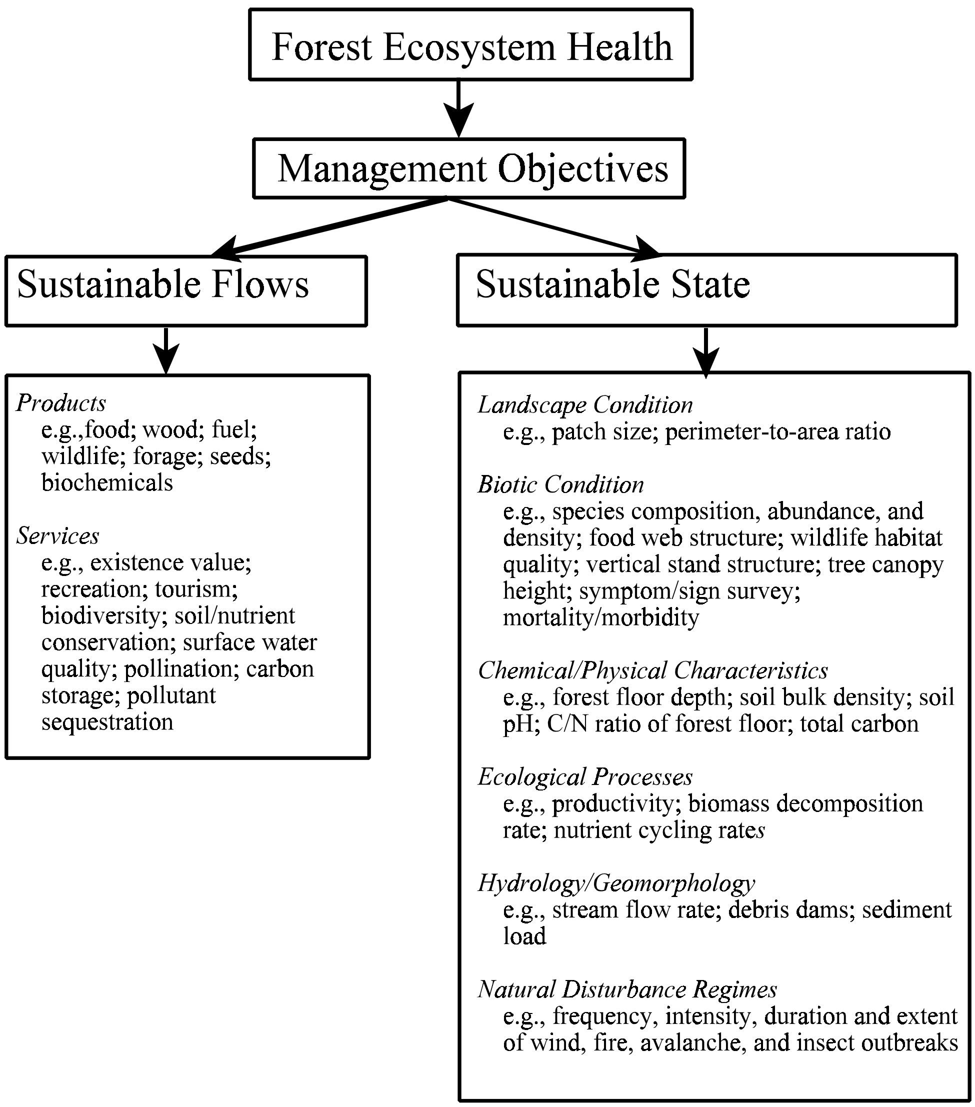


Figure 2. Two world views of forest system health. The "sustainable flows" view has an anthropocentric focus and measures "health" as the ability of forest systems to provide a sustained flow of forest products and/or forest services to human societies. The "sustainable state" view has both an anthropocentric and a biocentric focus and measures "health" as the ability of forest systems to sustain a certain state as defined by one or more of the ecological attributes.

case of a "sustainable state" focus, the emphasis is on the integrity of the ecological resource. Integrity involves the concepts of completeness (e.g., with reference to landscape, community, and species composition) and the ability of the resource to continue into the future (i.e., sustainability).

In this report, we focus exclusively on condition measures related to ecological integrity or "sustainable state" because these are a critical -- and largely missing-- link in the information base upon which environmental reporting can be built.

1.3 A Mandate to Report on Environmental Outcomes

Reporting on ecological condition provides a foundation for assessing the success of the nation's environmental protection efforts. Perhaps the most visible example of the Agency's need to report on environmental outcomes is the Government Performance and Results Act of 1993 (GPRA), which requires federal agencies to: develop specific goals and objectives; define performance measures to assess progress in meeting these goals and objectives; and report annually on these performance measures. In response to this mandate, the Agency developed a strategic plan (EPA, 1997; 2000) that defines the Agency's mission in terms of 10 environmental goals, with associated objectives, sub-objectives, and performance measures. However, the performance measures have tended to be administrative and stressor measures, with very few measures of environmental outcomes -- particularly ecological condition measures.

The Science Advisory Board (SAB) has long recommended to the Agency that it increase its focus on outcome measures, including measures of ecological condition. In its review of the Agency's draft Environmental Goals for 2000, a predecessor to the EPA Strategic Plan (1997; 2000), the SAB applauded the clear articulation of goals and measurable objectives, yet urged the Agency to seek measures more directly related to environmental outcomes (SAB, 1997b). In a 2000 report, *Toward Integrated Environmental Decision-making*, the SAB again recommended that the Agency give increased attention to the development and application of measures of environmental outcomes associated with regulatory and management programs (SAB, 2000).

While these recommendations are compelling in theory, they are difficult to implement in practice. Within the National Environmental Performance Partnership System (NEPPS), for example, both the Agency and state governments have attempted to generate a balance of administrative and outcome measures for use as "core performance measures." (For additional discussion of the NEPPS program as it relates to condition assessment, see Section 6.5.) In a presentation to the Ecological Processes and Effects Committee (EPEC) of the Science Advisory Board in July 1998, however, the Agency acknowledged the difficulty of developing these outcome measures. Part of the challenge the Agency faces in reporting on environmental outcomes is the dearth of condition assessments that address an appropriate array of ecological characteristics. A number of reviews conducted by EPEC during the past decade highlighted the need for -- and absence of -- information about fundamental ecosystem characteristics; e.g., SAB reviews of guidance for biological assessment of streams (1994) and lakes (1997a), landscape assessment (1995), the Index of Watershed indicators (1997c; 1999), watershed ecological risk assessment (1997d), and ecological research priorities (1997e; 1998). As a result, EPEC concluded that this recurring information gap has impeded the Agency's ability not only to plan research strategies and develop biocriteria, but also conduct ecological risk assessments and report on watershed condition.

In short, previous SAB reviews of Agency projects and programs, as well as summaries of the current state of regional ecological reporting, suggest a need for a generic organizational tool that will assist the Agency to systematically develop, assemble, and report on the fundamental characteristics of ecological systems, both regionally and nationally. The purpose of this report is to offer assistance in designing that organizational tool.

1.4 Contents of This Document

The following report provides an overview of a generic assessment and/or reporting system (Section 2) and a detailed list of ecological attributes that should be considered when assessing ecological condition. The list of ecological attributes is presented as a nested hierarchy so that it can be used to organize indicators and report on ecological condition (Section 3). Subsequent sections discuss the relationship between assessment of condition and assessment of stressor regimes (Section 4) and scientific issues associated with interpretation of indicator values (Section 5). The report also presents case examples to illustrate how the attribute list and framework might be used to strengthen Agency programs and, potentially, communication among programs (Section 6).

2. CONSTRUCTING A REPORT ON ECOLOGICAL CONDITION

2.1 Reporting Architecture

In order to foster consistent and comprehensive assessment and reporting on the condition of ecological resources, the Panel proposes a reporting framework in which information on 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, which is closely derived from Harwell et al. (1999), can be used as part of a reporting system (Figure 3) that contains the following major elements:

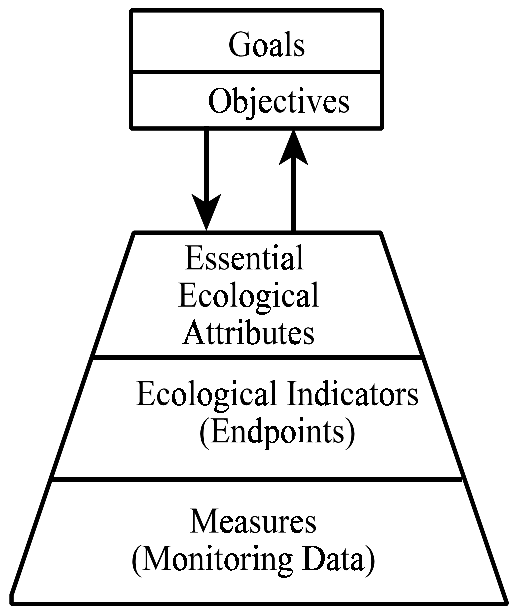


Figure 3. Proposed Architecture for Assessing and Reporting on Ecological Condition.

a) **Goals and Objectives**. Ideally, environmental management or restoration programs begin with a process to develop goals and objectives that combine societal values and scientific understanding, then articulate the desired ecosystem conditions that will result from the program(s). The proposed reporting framework can be applied to a variety of environmental program goals, including conservation, restoration, or risk assessment, associated with national, regional, or watershed scale programs. For those programs that have a less formalized procedure for developing goals, a process analogous to the "Planning" described as part of the Agency's Guidelines for Ecological Risk Assessment (EPA, 1998) might be used to identify the goals and objectives of the program.

b) **Essential Ecological Attributes**. Essential Ecological Attributes (EEAs) are the defining attributes of an ecological system or landscape (See Section 3). A list of EEAs and their associated subdivisions (Table 1) can be used as a checklist to help design management and assessment programs, and used as a guide for aggregating and organizing environmental information. The elements of the chart and its hierarchical organization are derived from a conceptual model of ecological system structure and function. Other valid methods of categorizing ecological characteristics could be derived.

c) **Ecological Indicators**. Ecological indicators (also called ecological endpoints) are measurable characteristics related to the structure, composition, or functioning of ecological systems; i.e., indicators of condition. Multiple indicators may be associated with each element in Table 1.

d) **Measures**. The measures are the specific monitoring variables that are measured in the field and aggregated into one or more ecological indicators. Additional descriptions of the measures and endpoints and their relationships to conceptual models are presented in Harwell, et al. (1999). These terms are also generally analogous to the endpoints and measures defined in the Agency's Guidelines for Ecological Risk Assessment (EPA,1998).

The proposed reporting framework provides a template for reporting on the success of national, regional or watershed-level environmental goals:

Example National Ecological Goals (Source: EPA Strategic Plan 2000)

By 2005, increase by 175 the number of watersheds where 80 percent or more of assessed waters meet water quality standards, including standards that support healthy aquatic communities.

Restore and maintain the chemical, physical, and biological integrity of the Great Lakes Basin Ecosystem, particularly by reducing the level of toxic substances, protecting human health, restoring vital habitats, and restoring and maintaining stable, diverse, and self-sustaining populations.

Example Regional-Scale Restoration Program Goals (Source: CALFED Bay-Delta Program, 1999)

Rehabilitate natural processes in the Bay-Delta system to support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities, in ways that favor native members of those communities.

Protect or restore functional habitat types throughout the watershed for public values such as recreation, scientific research and aesthetics.

Improve and maintain water and sediment quality to eliminate, to the extent possible, toxic impacts on organisms in the system, including humans.

Example Watershed Risk Assessment Goal (Source: EPA, 1996)

Reestablish and maintain water quality and habitat conditions in Waquoit Bay and associated wetlands, freshwater rivers, and ponds to (1) support diverse, self-sustaining commercial, recreational, and native fish and shellfish populations and (2) reverse ongoing degradation of ecological resources in the watershed.

The relationship among these components is also relatively straightforward. Measures (monitoring data) are aggregated into ecological indicators. Indicators are aggregated into the elements of the hierarchy of EEAs[1]. 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. It shows transparently how a large number of detailed indicators are synthesized into a single assessment of an ecological attribute, and it attempts to address all of the relevant attributes in a parsimonious set. Aggregated information on EEAs is based on scientific knowledge and judgment, yet is understandable – at least conceptually – to non-technical decision-makers and members of the public. A more complete discussion of the Essential Ecological Attributes, indicators, and measures – the components of the reporting system that are based on the ecological sciences – is presented in Section 3.

This reporting architecture is based on the assumption that societal values will dominate the selection of goals and objectives and that scientific understanding will dominate the selection of indicators, measures, and the methods of data aggregation. Figure 3 shows a clear separation between Goals and Objectives in the upper half and Essential Ecological Attributes, 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. They may change with improved scientific understanding, but should not change with the shorter term adjustments in objectives that are common among ecosystem management and restoration programs. 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 Essential Ecological Attributes and Objectives are unrelated, however. The EEAs provide an organized body of information from which one can assess a program's success in meeting <u>any</u> 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 Essential Ecological Attributes.

[1] How this aggregation occurs will vary among different types of programs and for different reporting systems. Options range from a mathematical index to the selective use of representative indicators.

Table 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
  - Extent/Distribution 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

2.2 Relationship to Other Reporting Frameworks

The Organization for Economic Cooperation and Development (OECD), an international organization that works to achieve growth and stability in the world economy, has developed a "Pressure-State-Response" (PSR) framework for environmental reporting that has been widely adopted. The PSR framework considers that "human activities exert pressures on the environment and affect its quality and the quantity of natural resources ("state"); society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behaviour ("societal response")"(OECD, 1998).

The framework presented here relates exclusively to a subset of environmental "state", i.e., to ecological condition assessments as defined in Section 1.2. Often, however, the goals and objectives of environmental programs relate to the management of stressors (such as particular chemicals or habitat alteration) in order to improve ecological condition. In these programs, reporting on the achievement of objectives will require assessment of ecological condition, the presence of stressors, and the relationship between the two. The framework presented here can be adapted to incorporate parallel information on stressors for this purpose (see Section 4).

The recent, growing interest in environmental condition assessments has spawned a great deal of work on development of indicators related to ecological condition and biotic integrity, as well as on methods for selecting appropriate indicators. At EPA, for example, the Science to Achieve Results (STAR) Program has awarded over 40 grants for the development of ecological indicators, the Environmental Monitoring and Assessment Program (EMAP) has continued to develop and test aquatic and landscape condition indicators, and EPA has released guidelines for evaluating and selecting ecological indicators for various applications (Jackson et al., 2000). The framework presented here attempts to show how these indicators can be assembled into a coherent picture of sustainable ecological condition. The indicators, in short, are prerequisites for the real-world application of this framework.

In addition, numerous local and regional ecosystem "report cards" have been developed, such as those covering the Chesapeake Bay (EPA, 1999; Chesapeake Bay Program, 2001) and the Great Lakes (Environment Canada and U.S. EPA, 1999). Because these efforts are tailored to specific sites, however, they have not provided easily transferable templates that can be used to design ecological condition assessments for other regions or other types of systems. Recent reviews of regional environmental report cards (Myers and Sharp, 1997; see also Harwell, et al., 1999) confirm that, although many report cards attempt to assess the status of ecological conditions and use the best available data, none uses a systematic framework that is conceptually based on the principles of ecology and ecological risk assessment, applies across spatial and temporal scales and ecosystem types, and can be adapted to any set of environmental management goals. One of the purposes of this report is to help fill this gap.

Two recent reports have attempted to create an overarching framework for reporting on ecological condition across the nation's ecosystems. The National Research Council, in *Ecological Indicators for the Nation* (NRC, 2000), proposes a list of indicators that can be measured reproducibly and aggregated nationwide to provide a concise snapshot of ecological condition. (Indicators that would differ in different systems, even though they might measure an analogous attribute, e.g., primary production, were omitted from consideration.) The report also discusses criteria for selecting national or regional indicators and appropriate methods for aggregating information into indicators.

Another effort to develop a framework for environmental reporting is being conducted by The Heinz Center with the support of eight federal agencies, as well as private foundations, corporations, and environmental advocacy groups. The Heinz Center framework will be used to generate periodic reports on the state of the nation's ecosystems. It targets six different ecological system types and specifies attributes for which indicators should be reported (The Heinz Center, 1999; in press). The attributes generally are consistent across system types, but — unlike the NRC's list — the indicators are not.

The framework presented in this report attempts to build on both the NRC and The Heinz Center efforts. The hierarchical list of Essential Ecological Attributes includes attributes that correspond to each of the indicators listed in the NRC report and also incorporates each of the attributes covered by The Heinz Center, with the exception of those relating to the production of goods and services explicitly for human use. The list presented here attempts to be more comprehensive, relate clearly to current conceptual understanding of ecosystem structure and function, and apply to a variety of ecological system types at several geographical scales. While the overarching conceptual model that the Panel has used to develop the Essential Ecological Attributes differs somewhat from those used by the NRC and The Heinz Center, the attribute categories can be mapped onto one another in a relatively straightforward way (see Table 2). For a more detailed analysis of the relationship of the indicators proposed by The Heinz Center effort and the EEA reporting categories, see Appendix A.

Table 2. Comparison of SAB Reporting Categories with NRC (2000) Indicators and The Heinz Center Indicator Categories

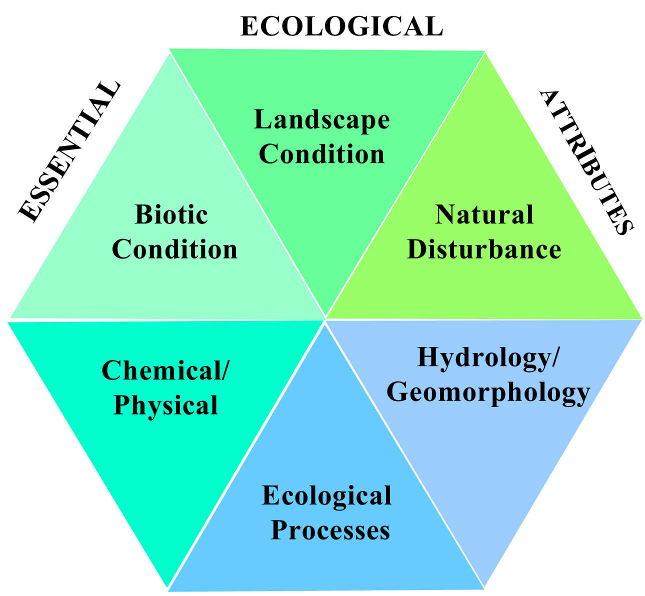
SAB Framework	NRC (2000)	The Heinz Center (In press) (See Appendix A for full list of indicators recommended by The Heinz Center)
LANDSCAPE CONDITION	**EXTENT AND STATUS OF ECOSYSTEMS**	**SYSTEM DIMENSIONS**
Extent	***land cover*** ***land use***	**Extent**
Landscape Composition		
Landscape Pattern and Structure		**Fragmentation and Landscape Pattern**
BIOTIC CONDITION	**ECOLOGICAL CAPITAL: BIOTIC RAW MATERIALS**	**BIOLOGICAL COMPONENTS**
Ecosystems and Communities **-Community Extent** **-Community Composition** **-Trophic Structure** **-Community Dynamics** **-Physical Structure**	***total species diversity*** ***native species diversity***	**Biological Communities**
Species and Populations **-Population Size** **-Genetic Diversity** **-Population Structure** **-Population Dynamics** **-Habitat Suitability**		**Plants and Animals**
Organism Condition **-Physiological Status** **-Symptoms of Disease and Trauma** **-Signs of Disease**		
ECOLOGICAL PROCESSES	**ECOLOGICAL FUNCTIONING (PERFORMANCE)**	
	land use	
Energy Flow **-Primary Production** **-Net Ecosystem Production** **-Growth Efficiency**	**Productivity, including** ***carbon storage*** ***net primary production*** ***production capacity***	**Ecological Productivity**
	lake trophic status	
	stream dissolved oxygen	**CHEMICAL AND PHYSICAL CONDITIONS**
Material Flow **-Organic Carbon Cycling** **-N and P Cycling** **-Other Nutrient Cycling**	***soil organic matter*** ***nutrient-use efficiency*** ***nutrient balance***	**Nutrients, Carbon, Oxygen**
	ECOLOGICAL CAPITAL: ABIOTIC RAW MATERIALS	
	***nutrient runoff* to coastal waters**	

CHEMICAL AND PHYSICAL CHARACTERISTICS		
Nutrient Concentrations **-Nitrogen** **-Phosphorous** **-Other Nutrients**		
Other Chemical Parameters **- pH** **- Dissolved Oxygen** **- Salinity** **- Organic Matter** **- Other**	 ***(stream oxygen)*** ***soil organic matter***	
Trace Inorganic and Organic Chemicals **-Metals** **-Other Trace Elements** **-Organic Compounds**		**Chemical Contaminants**
Physical Parameters		**Physical Conditions**
HYDROLOGY AND GEOMORPHOLOGY		
Surface and Groundwater Flows **-Pattern of Surface Flows** **-Hydrodynamics** **-Pattern of Groundwater Flows** **-Spatial and Temporal Salinity Patterns** **-Water Storage**		
Dynamic Structural Characteristics **-Channel/Shoreline Morphology and Complexity** **-Distribution and 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		
		HUMAN USE
		Food, Fiber, and Water
		Recreation and Other Services

3. ESSENTIAL ECOLOGICAL ATTRIBUTES

3.1 Rationale for the Selected Ecological Attributes

The Essential Ecological Attributes (EEAs)—Landscape Condition, Biotic Condition, Chemical and Physical Characteristics, Ecological Processes, Hydrology and Geomorphology, and Natural Disturbance Regimes— summarize the major ecological features in any system by capturing the relevant scientific information in a limited number of discrete, but not necessarily independent categories. These six generic ecological attributes represent groups of related ecological characteristics, as depicted in Table 1. The EEAs, categories, and subcategories are designed to apply to all ecological systems. Various types of ecosystems are differentiated by selecting appropriate indicators within each subcategory (or rarely, by selecting different subcategories or categories). The values measured for these indicators can then be aggregated either quantitatively or qualitatively to provide information about the "health" or integrity of the attributes represented by each subcategory and category. For a very concise picture of the state of integrity of the system as a whole, the information can be reduced to scores or qualitative descriptors for each EEA. In short, the EEA hierarchy is intended to help determine what to measure and then help to organize the information that is gathered.



The EEAs, categories, and subcategories in Table 1 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. This organizational scheme is not unique, however. In other words, it is one way to describe ecological systems, but other organizing principles could legitimately have been chosen.

The EEAs proposed here 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 (e.g., Bormann and Likens, 1979). 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)[2].

In order to subdivide pattern and process into EEAs, the Panel elected to highlight characteristics that often are overlooked by the Agency and by members of the public (such as landscape structure, disturbance, and ecological processes). For ease of use, the Panel grouped characteristics that are generally measured together (such as chemical and physical characteristics, hydrology and geomorphology, and biotic elements at a variety of hierarchical scales). The resulting EEAs are similar to those proposed by Harwell et al. (1999).

The relationships among the EEAs are complex, and all of the EEAs are interrelated; i.e., changes in one EEA may affect -- directly or indirectly-- every other EEA. Despite this interconnectedness, no single EEA is totally predictive of another, and no single EEA is a sufficient predictor of the state of the system as a whole. A salient example of the first observation is the recognition that chemical and physical characteristics alone do not predict biotic condition. An example of the second observation is that—despite the popularity of the proposition—measures of biotic condition cannot be used as a surrogate for ecological condition. Changes in other components of ecological condition, such as hydrology or landscape structure, may be significant but will not be reflected in measures of biotic condition until later.

In the Panel's view, the subdivisions of pattern and process represented by the EEAs are critical components about which information is required to characterize the condition of any ecological system. In order to test this assertion, the Panel conducted a few conceptual experiments. First, the EEAs were compared to an alternative construct often used to describe ecological systems. In addition to pattern and process, ecological systems can be described in terms of structure, composition, and function. Moreover, each of these characteristics is expressed at every level of ecological organization: from landscapes, to ecosystems nested within these landscapes, to communities, and so forth down to organisms and genes. The EEAs and their subcomponents were mapped onto structural, functional, and compositional characteristics at a variety of scales in order to assure coverage (see Appendix B). Second, the EEAs and their subcomponents were checked to determine whether they would be relevant at several geographic scales (ecoregion, 1000 km^2; regional landscape, 100 km^2; small watershed or ecosystem, 10 km^2; reach or stand, <1 km^2). In general, all of the components of Table 1 were

[2]The distinction between processes and patterns often is a temporal one. Processes (e.g., transfers of matter through ecosystems, community dynamics) may follow an element of pattern (chemicals, numbers of species) through time. Because of this relationship, patterns sometimes are measured as surrogates for processes, which often are more difficult to measure directly. For example, the biomass of invertebrates over space and time (a pattern) may be measured as an indicator of secondary production (a process).

relevant to each geographic scale[3]. Finally, the Panel determined that the EEAs and their subcomponents were applicable to a variety of ecological system types (see Section 6 and Appendix A).

For the most part, the reporting categories contain attributes that are altered directly by humans. Attributes generally not affected directly by humans–e.g., weather and large topographic features–may be included indirectly under Landscape Condition as measures of habitat extent and landscape structure.

[3]Exceptions occur, however. For example, very small geographic scales may not include landscape patterns.

3.2 Landscape Condition

The biotic elements of ecological condition are organized as a nested hierarchy with several levels--*landscape*, ecosystem or ecological community, species/population, organism, and genetic/molecular level–each of which should be incorporated in an assessment of condition (Noss, 1990; Angermeier and Karr, 1994). Within these categories of biological organization, it is useful to report on diversity, composition and other attributes of condition. In the proposed reporting framework, the Panel addresses the landscape attributes of condition in a separate EEA, rather than grouping landscape measures with other measures of Biotic Condition, primarily to draw attention to an often under-reported aspect of ecological condition. The separation also recognizes that abiotic factors are important determinants of landscape structure and composition.

> ***A landscape*** is an area composed of a mosaic of interacting ecosystems or habitat patches.

A landscape is an area composed of a mosaic of interacting ecosystems, or *habitat* patches (Forman and Godron, 1986), with the heterogeneity among the patches significantly affecting biotic and abiotic processes in the landscape (Turner, 1989). Habitat condition may reflect both abiotic features (e.g., slope, aspect, 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 (Fahrig and Merriam, 1985). 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 (McGarigal and Marks, 1993).

> ***Habitat*** refers to the set of conditions that make a site suitable for particular species (or taxa).

Patches comprising a landscape are usually composed of discrete areas of relatively homogeneous environmental conditions (McGarigal and Marks, 1993) and must be defined in terms of the organisms of interest. For example, in a landscape composed of equal parts of forest and pasture, a photophilic butterfly species would perceive the pasture areas as suitable habitat whereas a shade-tolerant species would prefer the forest. The concept of habitat quality for focal species is discussed further under Biotic Condition. At the landscape scale, the extent of broad land cover classes (e.g., forest, agriculture, urban/suburban, surface waters) can serve as surrogates of habitat extent for broad classes of species. When particular species or ecological communities are of interest, these broad land cover classes should be divided into finer subunits. For example, forests can be subdivided into types such as those delineated by the Society of American Foresters (e.g., jack pine, balsam fir, and aspen in boreal forest regions; Eyre, 1980). The National Research Council recently recommended the refinement of a land cover surrogate that could be used nationwide (NRC, 2000).

Both landscapes and habitat patches are dynamic and occur on a variety of spatial and temporal scales that vary as a function of each animal's perceptions (McGarigal and Marks, 1993). For instance, a long-lived and far-ranging bird will view its environment at broader spatial and temporal scales than a short-lived, flightless insect. These differences can be incorporated and used in landscape analyses by changing the spatial or temporal resolution of a database or model.

The Panel recommends that landscape indicators be reported in the following three categories: extent of each ecological system type; landscape composition; and landscape pattern/structure. The categories are summarized in Table 3 and discussed below.

a) **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 (Wilson, 1988; Saunders et al., 1991). Extent may be reported for broad land cover classes, for finer subunits, or both. In addition to area, the shape of habitat patches is an important consideration for many (e.g., edge-sensitive) species. Measures of habitat shape include the ratio of perimeter-to-area, core area, and elongation. Changes in landscape extent through fragmentation or aggregation of natural habitats can alter patterns of abundance for single species and entire communities (Quinn and Harrison, 1988; Bierregaard et al., 1992), and may pose a threat to biodiversity (Whitcombe et al., 1981; Skole and Tucker, 1993).

Habitat extent is often reported as a simple gain or loss. A more sophisticated method of assessing the importance of habitat is based on the needs of *focal species* (see Section 3.3). Through monitoring, the habitat needs of focal species can be analyzed and projections can be made to determine the type and amount of habitat needed for the species to have self-sustaining populations well-distributed throughout its range. The habitat created or maintained under any management scenario may be compared with the habitat needed for the viability of each focal species. The less adequate the habitat for each focal species, the greater the risk to other native species and to ecological integrity.

Focal species are a subset of species whose presence/absence and abundance can indicate the functioning (condition) of an ecological system.

b) **Landscape Composition.** Landscape composition can be measured by several metrics. The number of landcover or habitat types can serve as a discrete measure, but requires a clear definition of each type in such a way that they are not overlapping (e.g, forested land, agricultural lands, and edges between the two). It also is important to note the absence of habitats or native communities (e.g., early successional stages in a jack pine matrix ecosystem) that would have been expected on the basis of ecoregional characteristics[4]. Information on the largest patch size may provide insight into long-term population viability because populations are unlikely to persist in landscapes where the largest patch is smaller than that species' home range. Traditional diversity indices such as the Shannon Index and Simpson Index quantify diversity of habitat types. These indices first gained popularity as measures of plant and animal diversity and are easily applied to landscape diversity (O'Neill et al., 1988). Unfortunately, these indices convey no information about the structure and arrangement of patches within the landscape. For instance, a landscape composed of 90% forest and 10% pasture would yield the same landscape diversity index value as a landscape of 10% forest and 90% pasture. In addition, these diversity indices combine patch evenness and richness information, although these components are often more useful when considered separately. Evenness in the context of landscape diversity refers to the distribution of area or abundance among patch types. Richness, on the other hand, refers to the number of patch types present. Because many organisms are associated with a single type, patch richness may correlate well with species richness (McGarigal and Marks, 1993). Following this line of reasoning, Stoms and Estes (1993) outline a remote sensing agenda for mapping and monitoring biodiversity which focuses almost exclusively on species richness.

Recently ecologists have been mapping biophysical units or ecological land types in an effort to better define landscapes relevant to predicting the distribution of species and ecosystems (Anderson et al., 1998). These units draw upon digital data layers for three primary factors: elevation, topography (from digital elevation models), and lithology. Geology (parent material or substrate), elevation, slope, aspect, and moisture all are important factors in determining the distribution of vegetation.

c) **Landscape Pattern/Structure**. While some minimum area of native habitats in a landscape is necessary for maintaining population viability of native species, the spatial pattern of habitat also is important. Changes in pattern can occur either by natural processes (e.g., wildfires, windthrows) or as a result of human activities (e.g., urbanization, agricultural expansion). Natural fragmentation generally results in habitat patches with more irregular edges than human-created patches (Krummel et al., 1987). This pattern is clearly evident when one compares square agricultural fields to heterogeneous shapes of patches created by small fires. Natural disturbance and forest management practices can interact with existing landscape pattern to dramatically affect the risk of species loss (Gardner et al., 1993). Species that are most vulnerable are ones that become isolated as a result of landscape fragmentation and are also restricted to specific habitat types. Land management

Habitat fragmentation results when an area with one continuous land cover or habitat type is altered to a mosaic of different types.

[4]Often, native or dominant plant communities are used to identify habitats (e.g., in Gap analysis).

practices that increase the degree of landscape fragmentation can change the competitive balance among species, further jeopardizing the maintenance of regional native species diversity (Gardner et al., 1993).

Changes in ecosystem structure and function often depend as much on what happens in the area around the habitat of concern as they do on the size of the habitat and its relationship to other similar habitat. Indices that represent the spatial arrangement of habitat patches within a landscape have been developed from theoretical work in landscape ecology (e.g., Baker and Cai, 1992; Gardner and O'Neill, 1991; Gustafson and Parker, 1992; Krummel et al., 1987; O'Neill et al., 1988; Plotnick et al., 1993). Recent advances in remote sensing and geographic information systems (GIS) allow these methods to be readily applied over large areas.

Because no single index can capture the full complexity of the spatial arrangement of patches, a set of indices are frequently evaluated. Three of the more common indices are dominance, contagion, and fractal dimension (O'Neill et al., 1988).

Dominance, which is the complement of evenness, provides a measure of how common one land cover is over the landscape. Its value indicates the degree to which species dependent on a single habitat can pervade the landscape (e.g., the endangered Karner blue butterfly depends on the presence of its single host plant, wild blue lupine; Kirtland warblers are dependent on early successional patches of Jack pine). The contagion index measures the extent to which land covers are clumped or aggregated. Contagion is a useful metric for those species that require large contiguous areas of a particular land cover (e.g., carrion beetles which are affected by forest fragmentation; Klein, 1989). Fractal dimension uses perimeter-to-area calculations to provide a measure of complexity of patch shape. Natural areas tend to have a more complex shape and a higher fractal value, whereas human-altered landscapes have more regular patch structure and a lower fractal dimension (Krummel et al., 1987). This difference can influence the diversity of species that inhabit edges or require multiple habitats (e.g., large herbivores require both forests for cover and open fields for forage; Senft et al., 1987). The spatial arrangement of habitat patches also can be measured by the mean, minimum or maximum distance between patches. For some organisms such distance measures are critical determinants of the organisms' ability to cross between patches (Dale et al., 1994), although the type of intervening habitat is often critical to such movement or dispersal (e.g., presence of suitable "corridors").

In addition to landscape structure and composition, it is important to assess landscape function or habitat quality. As previously noted, habitat quality or suitability is an attribute that is assessed for particular species of interest and thus is discussed under the next section, Biotic Condition. For certain purposes, however, habitat quality also may be used as a screening device for reporting on habitat extent; only habitats that exhibit a certain degree of integrity or function would be reported.

Table 3. Landscape Condition

Category	**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 largest 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 seral stages; width of habitat adjacent to wetlands

3.3 Biotic Condition

For the purposes of this reporting framework, we define 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 the presence or absence of important elements, other aspects of composition, diversity, and structural elements relating directly to functional integrity (such as trophic status or structural diversity within habitats) are considered. Although many genetic characteristics are important to biodiversity, rates of evolutionary change, and fitness of individuals and populations (e.g., Landweber and Dobson, 1999), a detailed assessment of genetic characteristics presently is beyond the scope of most ecosystem management or assessment programs. Thus, only genetic diversity within populations of targeted species is included within the reporting framework.

a) **Ecosystem or Community Measures**. An *ecological community* is the assemblage of species/*taxa*[5] 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. Indicators of biotic condition at the ecosystem or community level include measures of community extent, community composition, trophic structure, community dynamics, and physical structure. These categories are consistent with the concept of "biotic integrity" as defined by Karr and Dudley (1981; Karr, 1991; 1993) and the Agency's guidance on biological assessment and biological criteria (e.g., EPA, 1996b; 1998b) (see Appendix C).

Taxa are any systematic groupings of organisms (e.g., species, genera, families, orders).

1. **Community Extent**. The spatial extent[6] of native ecological communities may be determined from satellite imagery and aerial videography. To enhance mapping and sharing of data on extent, the Federal Geographic Data Committee has adopted standard classification systems for different community types (e.g., for wetlands and deepwater habitats, Cowardin et al., 1979; for terrestrial vegetation, Grossman et al., 1998). Extent data also may be presented for non-vegetative communities of interest (e.g., coral reefs, oyster bars).

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[5]In many cases, individual organisms cannot be identified to the species level (e.g., because a great number of species have not yet been described, because reference specimens are not available, or because of a lack of taxonomic expertise). Thus, reporting on biodiversity often will be at the level of taxa, rather than species.

[6]The absence of native communities may be included here, if this information has not already been incorporated in the metrics relating to landscape composition.

2. **Community Composition.** A starting point for reporting on community composition is an inventory of the species/taxa found in the ecological system. Useful measures of composition include the total number of species or taxonomic units, their relative abundance, presence and abundance of native and non-native species, and information on the presence and abundance of focal or special interest species. *Focal species* are a subset of species whose presence/absence and abundance can indicate the functioning (condition) of an ecological system. The characteristics of focal species are discussed further under Species and Population Level measures of condition.

Both total species diversity and native species diversity should be reported (e.g., see NRC, 2000). Species/taxa richness often is used as a measure of community condition but must be used cautiously so as to identify or exclude the non-native species component. The contribution of non-native (introduced) species to richness should be evaluated because, for example, an increase in disturbance often leads to an increase in the number of invasive species, possibly leading to an increase in the total of number of species. Even when evaluating the richness of native species, it is important to consider the species composition. Fragmentation and an increase in edge in a community, for example, can lead to increased richness of edge-tolerant species and/or to a decrease in edge sensitive species, with a net loss of biodiversity on a regional basis. Sample measures of species composition and abundance related to non-native species would be the percent cover of naturalized exotics (e.g., forage grasses) or the percent cover of invasive species.

3. **Trophic Structure** refers to the distribution of species/taxa and functional groups across trophic levels. Measures of trophic structure include food web complexity and the presence/absence of top predators or dominant herbivores. One technique of ecosystem functional analysis uses functional feeding groups of aquatic invertebrates to characterize biotic integrity. The invertebrates are clustered across taxonomic lines according to their morphological and behavioral adaptations for acquiring a food resource. Relative proportions of different functional groups can serve as surrogates measures of ecosystem processes; for example, autotrophic state of a stream habitat is reflected in the invertebrate functional groups that utilize primary producers as their food resource (algal scrapers, vascular hydrophyte shredders, and algal piercers; Cummins and Klug, 1979). These food resource-based ecosystem attributes are very sensitive to land use changes.

4. **Community Dynamics** include inter-specific interactions such as competition, predation, and succession. Measures of biotic interactions (e.g., levels of seed dispersal, pollination rates, herbivory, and prevalence of disease in populations of focal species) provide important information about community condition. For example, unnaturally high levels of deer browsing in forested ecosystems may lead to decreased nesting success of ground nesting birds (e.g., deCalesta, 1994).

5. **Physical Structure** refers to the distribution of both biotic and abiotic physical structures within a habitat. In terrestrial systems, such measures usually will focus on physical attributes of the plant community (e.g., vertical stand structure, tree canopy height, and the presence of snags in forest systems). In aquatic systems, physical habitat structure may result from the presence of macrophytes (e.g., eel grass beds, marsh grasses) or abiotic structures (e.g., large woody debris in streams[7]). Although physical habitat structure is a characteristic observable at the landscape scale, smaller scale within-habitat structural attributes also are important for many species. For example, birds are particularly attuned to the size and branching patterns of trees within their habitats and numerous studies have shown low bird species diversity in even-aged forest stands relative to natural stands with greater structural complexity.

b) **Species or Population Level Measures**. Measures of the condition or viability of populations of species in an area are important indicators of biotic condition, yet monitoring the status of all species is impossible from a practical standpoint. To address this problem, some higher taxonomic level can be used, or a subset of species called *focal species* can be monitored. In addition, some "special status" species (such as threatened and endangered species, game

The Role of Focal Species in Ecological Systems

Focal species may be selected for a variety of reasons. For example, **keystone species** have disproportionate influences on ecological processes and other species and their absence or removal may have a cascading affect on other processes and species (Mills et al., 1993; Power et al., 1996). Examples include top predators (Paine, 1974; Terborgh, 2000), dominant herbivores (Naiman, 1988), and ecological engineers (e.g., beavers, prairie dogs, gallery-forming insects in large wood on the forest floor), all of which alter habitats and affect the fates and opportunities for other species (Jones et al., 1994; Naiman and Rogers, 1997). **Umbrella species** are species whose range of occupied habitats overlaps those of a disproportionate number of other species. Various indicators--such as range extent, sensitivity to disturbance, habitat selectivity, and rarity–have been developed to select umbrella species (e.g., Fleishman et al., 2000), but the application of this concept across taxonomic groups and regions may not be reliable (Andelman and Fagen, 2000). **Link species** are species that play a critical role in ecosystem processes such as flows of materials or energy within complex foodwebs (Dale and Beyeler, 2001).

[7]Aspects of aquatic physical habitat complexity associated with stream channel morphology (e.g., the presence of pools and riffles) also may be reported under Hydrology and Geomorphology.

species, sensitive species, and those that are vulnerable because of their rarity) should be monitored, whether or not they would otherwise be considered focal species[8].

Measures of condition at the species or population level include population size; genetic diversity within or among populations; population structure; population dynamics; and habitat suitability for focal species.

1. **Population Size** is one of the key measures of population health. Often, population size must be estimated by combining density estimates for samples of known size and proportion (of the area), stratified as needed to reflect spatial differences in density. Usually only adult population size is measured, due to difficulties in including juveniles in the estimates.

2. **Genetic Diversity** measures are important in assessing population condition because small population size can lead to inbreeding within a population, and this inbreeding can lead to an increase in the manifestation of deleterious and lethal mutations within a population. Various measures, such as the degree of heterozygosity, can be used to assess the genetic condition or health of a population. For example, reduced levels of heterozygosity and an increase in deleterious mutations led to poor breeding success in Florida panthers and a decision to bring in pumas from the western states to improve the genetic fitness and viability of the remaining population.

3. **Population Structure** includes demographic information such as population age structure and composition (e.g., number of juveniles or fledglings) and percentage of the population that is of reproductive age. These measures, combined with information on population dynamics (e.g., reproductive characteristics such as age at first reproduction) are used to estimate population viability by modeling population trends through time. A method used in fisheries involves comparing minimum reproductive size in a population with mean individual size; as the mean size in the population approaches the minimum reproductive size, the population is at severe risk of collapse. Changes in population patterns occur as a result of inter- and intra-specific interactions (community and population dynamics) and changes in physical and chemical aspects of the environment. For example, a large population of long-lived mussels below a dam may be composed entirely of mature individuals that are not able to reproduce because of changes in hydrology, water temperature, and/or other species (e.g., host fish) since the population was established in that location.

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[8]Species that are imperiled or vulnerable to extinction or extirpation from an area may or may not be on official federal or state lists threatened species. For example, some states have no endangered species legislation and some species groups (e.g., plants and inv listed in proportion to their endangerment. Lists of vulnerable species are maintained by state natural heritage programs and non-g (e.g., NatureServe, International Union for the Conservation of Nature or IUCN).

4. **Population Dynamics** includes measures of reproductive output (e.g., frequency of reproduction, litter size, fledgling success) and survivorship (e.g., of different age classes). Although population viability can be measured from time series data on population size alone, increasingly accurate predictions of viability can be obtained by using information on population structure and dynamics. Population dynamics also are influenced by the processes of emigration and immigration, and these processes are influenced in turn by geographic isolation. Populations may be usefully be characterized as "sink" or "source" populations, depending on whether they are net exporters of propagules or depend on emigration.

5. **Habitat Suitability.** The characteristics that define habitat suitability will differ depending on the organism(s) of interest. However, parameters of habitat suitability should reflect the basic needs of a species for food, water, cover, reproduction, and, in some cases, social interactions. For example, important variables for fish habitat would include water temperature and flow velocity, dissolved oxygen level, shading, the presence of certain substrate types, and access to available food. Grassland bird habitat parameters might include grass stem height and density, and the extent of residual vegetation. Alligator habitat might be characterized by the availability and depth of open water in marsh areas and the degree of substrate exposure under low water conditions. Habitat suitability is a critical component of efforts to predict the occurrence of species.

Habitat analysis is used routinely in assessing the extent of mitigation required when wetlands are taken out of service, and for assessing the environmental impacts of proposed land and water development projects (see, for example, Fish and Wildlife Service, 1981). Habitat assessment models exist for various types of fish and wildlife species, including over 150 Habitat Suitability Index models published by the U.S. Fish and Wildlife Service. Because of the array of habitat requirements exhibited by species of interest, habitat quality measures may be reported under a variety of EEA categories. However, information on habitat quality for particular species of concern should be considered in assessing the viability of populations of those species in an area.

c) **Individual Organism Measures of Biotic Condition**. 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, or symptoms of disease in a forest). Measures in this category are primarily physiological, toxicological, or molecular in nature and have been divided into physiological status, and symptoms and signs of *disease* or *trauma*. Impaired organism condition indicates biological resources at risk due, for example, to insufficient food supply, sub-lethal exposure to contaminants, or disease or parasites.

1. **Physiological status** is the general condition of an organism, including the functioning of tissues and organs. Example measures include respiratory rate; growth rate; enzymatic activity (including biomarkers, such as induction of detoxification enzyme activity, that signal exposure to toxicants); and measures of nutritional status. In fisheries, the ratio of mass to length often is used as a measures of individual condition, as compared to the mean of a population at large.

Disease is abnormal physiology caused by biotic, chemical, or physical agents.

2. **Symptoms of disease or trauma** include the responses of target organisms to stress, infection, infestation, or injury. Examples of important symptoms include changes in behavior and/or gross morphology, the presence of tumors and lesions, and defoliation and crown die-back (for trees). Examples of trauma include the presence of scarring on manatees from collisions with boat propellers and scarring of tree trunks by harvesters.

Trauma is a condition of abnormal anatomy or morphology caused by physical, chemical, or biotic agents.

3. **Signs of disease** are evidence of the presence of agents capable of causing abnormal physiology in the target organism. Example measures include the presence of pathogens (e.g., bacteria, fungi, protozoa, nematodes) and insects on or in target organisms, and tissue burdens of xenobiotic chemicals (i.e., organic compounds that are foreign to the organism being sampled). Some naturally occurring substances, such as copper and selenium, are required for normal physiological function in many organisms; yet, in excess, these substances may cause physiological dysfunction. Tissue concentrations of these essential substances may be considered either measures of physiological status or as a sign of disease, depending on whether nutritional deficiency or toxicity is the relevant concern.

Table 4. Biotic Condition

Category	Subcategory	Example Indicators and Measures
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[1]	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[1]	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

[1] Also may be reported under Ecological Processes

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

The Chemical and Physical characteristics included here are measures of physical parameters (such as temperature) and concentrations of chemical substances that are naturally present in the environment. These attributes have received substantial public attention because they are the subject of pollution laws (Clean Air Act, Clean Water Act, and the like) that place a great deal of emphasis on measurement and reporting of key physical and chemical parameters within ecosystems. For example, under Section 305(b) of the Clean Water Act, states are required to report annually on the status of their surface waters. Water quality criteria are used to determine whether a given water body or stream meets the designated use or is "impaired." Similarly, National Ambient Air Quality Standards established under the Clean Air Act are used to judge the quality of ambient air. The advantages of such systems are that they utilize data that are reasonably easy to collect and for which there are standardized measurements and consistency of interpretation. As a result, standard lists of parameters have been developed and are routinely reported by each state, the importance of each parameter has been well researched, and data may be available[9]. We point out, however, that chemical measurements by themselves do not provide a comprehensive picture of ecosystem integrity.

In general, the parameters listed under this EEA are standard components of monitoring programs, because they are natural components of ecosystems within certain ranges, and they are pollutants (*stressors*) at other concentration ranges. Monitoring for pollution control usually covers many man-made chemicals (xenobiotic compounds) in addition to the parameters listed here; these may legitimately be and often are included in condition assessments.

> *"A **stressor*** is any physical, chemical, or biological entity that can induce an adverse response." (EPA, 1998)

The proposed reporting framework includes reporting categories for nutrients, trace inorganic and organic chemicals, other chemical parameters, and physical parameters. Because legislative mandates and monitoring programs are separated by environmental compartments (air, water, sediment, soils), many assessments and reports will include a separate section for each compartment. In other words, all of the categories would be reported for air, then all categories would be reported for water, and so forth. On the other hand, a report that integrates the various compartments also may provide insights.

[9]The Panel notes, however, that the U.S. General Accounting Office recently reported that only 19 percent of the nation's flowing waters were assessed in the most recent Clean Water Act 305(b) national water quality inventory (GAO/RCED-00-54). Additional information soon will be available from the USGS National Ambient Water Quality Assessment Program for about one-half of the conterminous United States.)

Although the categories in Table 5 are generally applicable, the specific chemical/physical parameters that should be included in a particular reporting scheme will vary depending on the spatial scale of the assessment and on whether the system being assessed is fundamentally aquatic, terrestrial, or a mosaic of different ecosystem types. Note that chemical fluxes and mass balance indicators are reported under the Ecological Processes EEA. Similarly, descriptors of physical habitat quality and type are included in the Hydrology and Geomorphology and/or the Biotic Condition EEAs.

a) **Nutrient concentrations**. Nutrients are elements required by plants and animals to carry out their life functions. The establishment of a food web starts with autotrophic organisms, who have the ability to produce organic matter from inorganic constituents, among which are the essential elements we call "nutrients." Concentrations of nutrients, including phosphorus, nitrogen, and potassium, and micronutrients (e.g., copper, zinc, and selenium) provide important information about the condition of environments as these chemical constituents may be limiting if available in too small a quantity and may lead to undesirable consequences if present in too great a quantity. Phosphorus, for example, is often the limiting nutrient in lakes. In estuarine and coastal ecosystems, nitrogen is often a limiting nutrient and anthropogenic loadings of nitrogen may lead to over-enrichment and eutrophication. Similarly, nitrogen is most often the limiting mineral nutrient in terrestrial ecosystems. In addition, the balance between the amount of carbon (the energy currency) and nitrogen (the nutrient availability currency) is a key parameter (C/N ratio) in determining the status of ecosystems and their productivity. Measures of nutrient cycling are discussed under the Ecological Processes EEA.

b) **Trace inorganic and organic chemicals**. This reporting category includes metals and other trace inorganic chemicals, as well as organic chemicals[10]. Assessing the ecological significance of chemicals in the environment requires an understanding of naturally occurring levels of specific chemicals in an ecological system. Therefore, obtaining baseline information on a broad spectrum of metals and organic chemicals in environmental samples is an important step in ecological assessments, whether or not their concentrations are elevated by pollutant discharges. For some chemicals, attention also should be given to specific fractions known to be of greatest ecological importance (e.g., measures for trace metals should include both total and acid extractable metals to provide insights on bioavailability and availability shifts over time). As noted above and in Section 4, ecological condition assessments may include or exclude xenobiotic chemicals and chemicals targeted because of their potential toxicity, persistence, and/or tendency to bioaccumulate in the tissues of organisms and biomagnify in a food web. If included, such parameters logically would be incorporated into this subcategory.

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[10]Some chemicals in this category (e.g., zinc and copper) are essential in trace amounts and also may be included in the nutrients subcategory, particularly if their concentrations may be limiting.

c) **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. In aquatic environments, measures might include alkalinity, biochemical oxygen demand (BOD), dissolved organic carbon (DOC), and water transparency.

d) **Physical parameters**: Physical measures, many of which have been routinely collected for years, are an important complement to other measures of physical habitat. Examples are provided for soil and sediment environments, as well as for aquatic environments and air.

Table 5. Chemical and Physical Characteristics (Water, Air, Soil, and Sediment)

Category	Subcategory	Example Indicators and Measures
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

3.5 Ecological Processes

In this reporting framework, we define Ecological Processes as the metabolic functions of ecosystems – energy flow, elemental cycling, and the production, consumption and decomposition of organic matter-- at the ecosystem or landscape level. In the proposed reporting scheme, biological processes at the species, population and community levels, including gene flow associated with community and population dynamics, are grouped with other biological measures under Biotic Condition because these processes generally are assessed together. Biological processes, however, legitimately may be incorporated under the Ecological Processes EEA.

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 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. Using Lindemann's (1942) trophodynamic model of ecology, the metabolic functioning of ecosystems can be conceptually divided into flows of energy and flows of materials (including organic and inorganic matter). The balance between these flows evolves in ecosystems to obtain "a self-correcting homeostatis…" (Odum, 1969). Condition reporting that includes ecological processes allows us to examine how human perturbation of ecosystems has affected this ecological integrity.

Although conceptual models of ecosystem functioning have included flows of energy and materials for over 100 years (Forbes, 1887), these ecosystem processes are used less often in environmental reporting than are static measures (like standing stock of biomass or chlorophyll) because of the inherent difficulty in capturing rate measurements in summary-type, integrative metrics. Process-level measurements also often have inherently higher variability than static measurements, and cost more to obtain.

Notwithstanding these complications, improved reporting of ecosystem processes will require increased use of material and energy budgets, rather than simply concentration measurements. Some indicators of material and energy flow are amenable to repeated sampling through time of a number of statistically-chosen individual sites–the approach taken by EPA's EMAP. Characterizing and reporting on ecological processes often is best accomplished using multi-tiered monitoring systems in which integrative ecosystem-level measures are coupled with detailed examination of processes at smaller spatial scales (e.g., Hubbard Brook Experimental Forest and other National Science Foundation Long Term Ecological Research sites, Canada's Experimental Lakes Area). A multi-tiered approach has been advocated by the White House's Committee on Environment and Natural Resources (CENR) and incorporated into some EMAP programs. A commitment to small-scale, intensive, long-term process-based monitoring programs within larger monitoring studies will continue to strengthen the scientific basis for indicators[11].

The key attributes of energy and material cycling in ecosystems are gross and net ecosystem productivity, the efficiency of energy transfer through food webs, and flows of carbon and nutrients (commonly referred to as biogeochemical cycling). Many of the examples listed below and in Table 6 are taken from the NRC's recent publication, *Ecological Indicators for the Nation* (NRC, 2000). However, the Panel stresses, as did NRC, that adequate indicators are not yet available for all of the key attributes of commonly held conceptual models for energy and material flows in ecosystems.

a) **Energy Flow.** The flow of energy between trophic levels and the interaction between heterotrophic and autotrophic components are universal features of ecosystems (Odum, 1969). Thus energy flow includes the concepts of both productivity and growth efficiency. Production can be conceptualized and reported in a variety of ways. Gross primary production is the amount of carbon fixed by an ecosystem as a result of photosynthesis. Net primary production is the difference between energy capture (photosynthesis) and metabolic processes (respiration) in plants alone. Net ecosystem production subtracts energy loss through the metabolism of heterotrophic organisms, including decomposers and consumers. In general, indicators of ecosystem production are fairly mature relative to indicators for other ecosystem processes.

1. **Primary Production.** Measures of gross and net primary production are diverse in scale and methodology, and range from estimates of production made from standing chlorophyll stocks or nutrient concentrations, to direct measurements of primary production in enclosed containers.

2. **Net ecosystem production** is the difference between whole-ecosystem primary production and respiration. Estimates of net ecosystem production indicate whether an ecosystem is self- supporting via primary production within the system boundary or whether organic matter must be imported across the system boundary in order to sustain biological integrity. NRC (2000) recommended that net ecosystem production be assessed through net ecosystem organic carbon storage, or the change in the total amount of organic carbon in an ecosystem per unit time. Measures of carbon storage (e.g., carbon sequestered in soils and vegetation) are critical to calculating CO_2 loading of the atmosphere and associated alteration of global climate. In forested ecosystems, the

[11]The choice of scales is of key importance in the examination of ecological condition and, therefore, in the design of indicator programs for ecological processes (NRC, 2000). Estimates of metabolic function must be made on temporal and spatial scales that are appropriate to the growth rate and spatial distribution of the organisms driving the process (often microorganisms with rapid growth rates), and to disturbance regimes that affect those organisms (cf. Hutchinson, 1967).

change in the standing stock of trees (in non-harvested forests) plus the change in organic matter content of soils provides a measure of net ecosystem production. Key ecosystem products (e.g., wood, fishery yields, or crop production) also traditionally have been used as measures of ecosystem production. Although these are valuable indicators for ecological products that are desirable to humans, they should not serve as sole surrogates for measures of whole-system net production. In aquatic ecosystems, production-to-respiration (P/R) ratios are commonly obtained from the change in oxygen or carbon dioxide fluxes over light/dark cycles. Local and satellite-based measures of CO_2 flux from ecosystems are somewhat less well developed, but may provide excellent integrated measurements of net ecosystem production.

3. **Growth Efficiency**. Ecosystem growth efficiency is a fundamental attribute of ecosystems, defining how well energy and carbon are transferred through food webs. The concept of growth efficiency arises from Lindemann's (1942) model of the efficiency of energy and material transfer between trophic levels, i.e. from primary producers to top consumers. It also includes the efficiency of energy and material transfer through decomposition and microbial grazers (i.e., the microbial loop; Azam et al., 1983). By comparing primary production with net ecosystem production, a measure of net ecosystem growth efficiency can be obtained.

Integrative indicators are needed to show how production is translated and distributed among trophic levels. In aquatic ecosystems, for example, high productivity at the bottom of the food web without translation to higher trophic levels may result in ecosystems that are less desirable to humans (e.g., more algae, fewer fish). Measures of growth efficiency often are confined to upper trophic level production, especially production of organisms with direct value to humans (e.g., game fish). These measures should be broadened to include wider measures of energy transfer within food webs.

b) **Material Flow.** Key materials in ecosystems include organic matter, and inorganic nutrients (e.g., nitrogen and phosphorus) and micronutrients (such as selenium and zinc). The flows of these materials in ecosystems are often referred to as biogeochemical cycles. Material and energy flow are linked processes and many indicators provide information on both, especially for carbon flow.

1. **Organic Carbon Cycling**. All known life is based on carbon, and carbon cycling—from carbon dioxide, to algal or plant biomass, higher trophic levels, and microbial decomposition pathways— is a fundamental ecological process. Characterization of carbon cycling would include input/output budgets, gross and net organic carbon production, and efficiency of organic carbon transfer through the food web. Net ecosystem production (see above) is a commonly used, but incomplete indicator of organic matter cycling. Increased attention is being given to the quantity and

quality of organic matter in ecosystems, and the influence of organic matter quality on ecosystem integrity. The Panel encourages the development of integrative measures of organic carbon quality and trophic transfer. Additionally, we recommend that, for the many aquatic systems that depend on allocthonous sources of organic carbon, organic carbon inputs should be included in materials budgets along with measures of nutrient inputs.

2. **Nutrient Cycling**. Concentrations of nutrients are commonly measured in ecosystems but the content of nutrients in various ecosystem compartments, the rates of transfer among ecosystem compartments, and the mechanisms governing those transfers are less often examined. Additions to the ecosystem and losses from the ecosystem over time are critical parameters to define in order to evaluate ecological integrity and sustainability. Highly complex pathways of nutrient cycling for elements like nitrogen underscore the need to define rates of nutrient cycling with attention to the importance of time. Nitrogen concentrations in plant tissues can vary over the life of the plant, over the growing season, and among years for perennial vegetation. Knowing a single concentration at one point in time provides limited information on the status of nitrogen accumulation or depletion in the ecosystem. Forests can at once accumulate nitrogen in the soil and forest floor while simultaneously becoming more nitrogen limited for forest growth. Measuring the "available" pool of either a macronutrient or micronutrient in the soil does not provide information on what total pools of these constituents might be present or how that availability might change (either providing more of a needed nutrient or creating conditions of detrimental excess) if environmental conditions change. In short, understanding nutrient cycling rates illuminates both the condition of an ecosystem and its potential response to disturbance. Defining the bounds of the ecosystem measured is a critical component of defining nutrient budgets and cycling.

Outputs from one environment (habitat) can affect the receiving environment (habitat); for example, nitrogen outputs from the Mississippi River drainage enter the Gulf of Mexico and are associated with hypoxic events caused by phytoplankton growth and decay. The feasibility and utility of input-output studies were demonstrated in the Hubbard Brook studies, which used the properties of rivers to converge into a single output stream to monitor a watershed’s outputs. By comparing precipitation inputs to outputs of harvested and intact forests, the researchers discovered acid precipitation.

Measures of nutrient cycling should include input/output mass balance (e.g., for nitrogen, phosphorus, and other nutrients), identification of dominant nutrient cycling pathways, and nutrient use/efficiency balance. Seitzinger et al. (2000) have developed large-scale nutrient budgets, based on inputs from rivers and coastal areas to the oceans, that will provide a basis for examining global and regional changes in nutrient cycling.

Table 6. Ecological Processes

Category	Subcategory	Example Indicators and Measures
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)
Biological Processes (Note: Also may be reported under Biotic Condition)	Community Dynamics	e.g., predation rate; successional state; pollination rate; herbivory
	Population Dynamics	e.g., birth and death rates; reproductive or recruitment rates; dispersal and other movements

3.6 Hydrology/Geomorphology

The hydrology and geomorphology characteristics of ecological systems reflect the dynamic interplay of water flow and landforms. In river systems, for example, attributes such as 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 and whether the natural succession or transition from one habitat type to another is maintained. These underlying physical processes are disrupted when rivers are dammed, streambeds are channeled into concrete banks, and large percentages of flow are taken out of the river for human use.

The geomorphic pattern of stream/river habitat and the hydrology that sets, maintains, and reforms it serve as the physical template upon which the life cycles of running water organisms are overlain. That is, the deterministic life cycles of aquatic organisms are adapted to the most probable states of a stochastic system. For example, some aquatic insects have evolved such that the time of their most vulnerable life stages coincides with the most probable period of stable flows over the long term. Further, females of many aquatic species deposit their eggs in areas where re-aeration keeps water well-oxygenated, thereby enhancing egg survival. Thus, changes in hydrology and geomorphology provide important information about future Biotic Condition and Landscape Condition.

In this sample hierarchy, Hydrology and Geomorphology are divided into three interrelated components: water flow; dynamic structural characteristics, and sediment transport. Water flow regimes affect sediment movement and patterns of erosion and deposition. 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 water and sediment flows. They also influence water flow patterns and availability of sediment for transport. While the three-part division is to some extent arbitrary, it is a useful construct to assure that essential water-related habitats (e.g., gravelly riffles, deep pools, nearshore shaded areas, floodplains) and the dynamic physical processes that sustain them are not overlooked in ecosystem assessments. Some categories included in Hydrology/Geomorphology--such as pattern of surface flows, channel complexity, and distribution and extent of connected floodplain–also may be reported as elements of Landscape Condition.

a) Water Flow. Surface and groundwater flows determine which habitats are wet or dry and when, and water flows transport nutrients and contaminants. 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. The category of surface and groundwater flows therefore includes the amount, timing, flow direction, and variability of water flows.

1. Pattern of surface flows. In rivers, a natural flow regime "organizes and defines river systems" (Poff et al., 1997). Even where water flows are regulated, maintaining a natural pattern of variability – if not flow magnitude – helps to support native species and a diverse array of habitats. Patterns of flow variability also are directly related to aquatic community structure and help maintain native species. Detailed indicators of the magnitude, frequency, duration, timing, and rate of change of river flows have been developed (Richter et al. 1996; see also Poff et al., 1997 and Richter et al., 1997 for a discussion of the underlying conceptual model). Although simpler surrogates may be used, particularly for other aquatic (non-riverine) and terrestrial systems, an effort should be made to capture the low-flow and high-flow amount, timing, and variability of surface flows. Note that periodic floods (which maintain habitat diversity, affect sediment particle size distributions in the channels and in the floodplains, and provide the disturbances that generally favor native species) are also treated under Natural Disturbance Regimes and could reasonably be reported in either category.

2. Hydrodynamics. The velocity and direction of water flows determine the movement of nutrients and contaminants in both surface and groundwater systems and have led to numerous adaptations of attachment and feeding among running water organisms. In estuaries, circulation and mixing are controlling physical processes that determine residence times of pollutants and nutrients, affect the biomass and community composition of plankton, and help determine the distribution of aquatic and wetland habitats.

3. Pattern of groundwater flows. Groundwater is of interest because it supplies water and chemicals to terrestrial and aquatic systems. It is also becoming more widely recognized as an important ecosystem in its own right. Relevant attributes therefore include the transfer of groundwater to surface systems, the mass balance of groundwater in an aquifer, and the rate and direction of water movement within an aquifer.

4. Spatial and temporal salinity patterns. In brackish systems such as estuaries and brackish wetlands, patterns of salinity are determined by water flows and mixing characteristics (by-products of hydrodynamics and geomorphology) and in turn determine habitat suitability for biotic communities. Ideally, salinity patterns should remain within natural ranges and should vary through time in a pattern consistent with natural conditions. This parameter may be incorporated within the Chemical/Physical EEA, but is cross-listed here in order to highlight its importance in certain system types.

5. Water storage. Water storage refers to the amount of water in a lake or aquifer. For lakes, wetlands, and aquifers, water storage integrates surface and groundwater flows. In the surface systems, fluctuations in water storage determine the area inundated and influence shoreline and wetland vegetation patterns. In aquifers, water storage determines the extent of surface water ponding, in addition to flow rate and direction. In extreme circumstances, depletion of water in an aquifer can cause the supporting structure to collapse, destroying the aquifer's storage capacity.

b) Dynamic structural characteristics. Maintenance of the diversity of natural habitats in aquatic systems is a dynamic process involving variations in water flow, erosion and deposition of sediments, and transport of other materials. Where these processes continue to operate, specific structural patterns can be observed in the streambed (or lakebed or bottom terrain of estuaries) and banks (or shoreline). Accordingly, dynamic structural characteristics reflect the maintenance of these underlying processes, and they provide direct information about the quality and diversity of habitats.

Dynamic structural characteristics overlap to some degree with the more stable structural characteristics included under Landscape Condition. The dynamic characteristics are grouped with hydrology here, because hydrology and fluvial geomorphology are closely related in aquatic systems and are often neglected in assessments of ecosystem condition. In terrestrial systems, however, the attributes of habitat complexity, connectivity, and topographic relief tend to be more stable and may logically be included (and aggregated with other attributes) under the Landscape Condition category.

Although the structural characteristics are divided here into several subcategories, they can be assessed as a group and combined with information on material transport, as in EPA's Rapid Bioassessment Protocols (Barbour et al., 1999), the EMAP, and the National Ambient Water Quality Assessment Program (NAWQA) program of the USGS.

1. Channel morphology and shoreline characteristics. Shoreline and channel characteristics are significant indicators of habitat quality for aquatic organisms. The inside of bends -- where banks and channel bottom are eroded and sediment is transported away -- provide deep water areas for passage or temporary refuge for organisms, such as migrating salmonid fishes; the outside of bends -- where flows are reduced and sediments are deposited -- provide areas for establishment of organisms with longer residence times. As the inside bends continue to erode, oxbows and backwaters can develop which contribute significantly to channel complexity (see below). The relationship of the vegetation on the banks, the riparian zone, to the stream channel is a critical feature of aquatic habitats. The vegetation can provide shade that limits aquatic plant growth and moderates water temperatures; the roots contribute, along with the nature of the soil material, to bank stability; and large wood derived from bank vegetation can provide some of the best in-channel habitat available to organisms. In fact, in active channels dominated by fine sediments, large wood may constitute the only stable habitat available to invertebrates.

2. Channel complexity. Stream islands, their associated point bars, and braids[12] constitute channel complexity that often confers important biotic diversity on a river system. Islands and braids result from differential cutting of the channel and deposition of sediment downstream from obstructions such as patches of exposed bed rock, large boulders, or woody debris. Both islands and braids increase the edge habitat where terrestrial or semi-aquatic vegetation can significantly influence the community structure of the aquatic biota. For example, braids essentially extend riparian plant cover found along smaller headwater channels to larger, wider river reaches. Channel complexity in marshes and river floodplains increases the amount of edge habitat and allows for the interface of different plant assemblages and invertebrates that require the different flow regimes that occur on the inside vs. outside of meanders in such channels.

3. Distribution and extent of connected floodplain. For many aquatic organisms, the off-channel or seasonally wetted habitats can be of utmost importance. These areas of interface between aquatic and terrestrial habitats provide such qualities as refugia of reduced flow during high discharge periods in streams and rivers, and reproduction (e.g., fish spawning) or feeding areas for aquatic animals when access from the main water body is available. Isolation of rivers, lakes, or estuaries from their associated floodplains or wetlands by diking can greatly reduce productivity of the aquatic biota. Connected floodplains also are important for attenuation of the impact of peak water flow on downstream areas, recharge of groundwater aquifers, and deposition of sediment. Similarly, coastal wetlands connected to estuarine environments provide natural attenuation of tidal and storm surge energy, reducing coastal flooding and erosion.

4. Aquatic physical habitat complexity. In aquatic systems, several specific structural characteristics are associated with instream habitat type and condition. These include, for example, areas of shaded riparian habitat (that moderate temperature, reduce aquatic primary production, and provide carbon inputs from dropping leaves), presence of large woody debris (that provides areas to rest and hide), and alternating patterns of riffles, runs and pools (that may provide clean spawning gravels and feeding areas). Maintenance of these features can be critical to support of native communities.

c) Sediment and other material transport. A wide variety of underwater and near-shore habitats (e.g., wetlands, early successional states in riparian areas) is maintained by the pattern of sediment and debris movement, and native species have adapted accordingly.

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[12]Point bars are composed of coarse sediments deposited in areas of reduced water velocity, e.g., on the down-stream side of islands. Braids are secondary channels connected to or part of the main flow channel.

1. Sediment supply and movement. The transport and storage of sediment are major forces that determine the distribution of instream and wetland habitats. Biologically healthy rivers are usually characterized by an approximate balance between scour and deposition of sediments. If deposition significantly exceeds transport, then reliable, stable habitat for sessile invertebrates may be buried and gravels where eggs are deposited by spawning fish may become silty. On the other hand, excessive scour can remove the very sediment required to support the attachment or spawning activities.

2. Particle size and distribution. Sediment particle size has been shown repeatedly to have significant influences on aquatic organisms. Coarse sediments are used for attachment by many aquatic invertebrates, the intermediate sizes are important for many spawning fish, the fine sizes are selected for burrowing and tube construction by invertebrates, and very fine sediments (silts and clays) may be ingested by many invertebrates that derive nutrition by digesting the bio-films that adhere to the particle surfaces. The sediments of the channel bed are distributed in accordance with the hydraulic conditions that deposited them, with coarse sediments in areas of higher flow and finer particles in lower velocity drop zones. The aquatic organisms will be distributed in accordance with their predictable sediment particle size requirements.

3. Other fluxes. Habitat complexity and productivity in rivers, lakes, wetlands and estuaries are maintained, in part, by fluxes of water, sediments, nutrients, organic matter (in allocthanous systems), and large woody debris. This category is designed as a catch-all for the items, such as large woody debris and other carbon inputs, that may not be captured elsewhere in the reporting hierarchy.

Table 7. Hydrology and Geomorphology

Category	Subcategory	Example Indicators and Measures
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 (rivers)

3.7 Natural Disturbance Regimes

Over sufficient time scales, all ecological systems are dynamic in nature. This dynamism results in part from 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, nonnative invasive species introduction, volcanic eruptions, earthquakes and avalanches.

White and Pickett (1985) define a disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resource, substrate availability, or the physical environment." Given sufficient knowledge of the natural history of a region, patterns of natural disturbance regimes can be described. The frequency, intensity (i.e., degree of disturbance), extent (i.e., spatial coverage), and duration of the events taken together are referred to as the "disturbance regime." An assessment or report on the condition of an ecological system should address each of the disturbance regimes relevant to that system.

Disturbances are ecologically important when the imprint they leave on the ecological system is large in area or persists for a very long time, or when the disturbance is an integral part of the ecological system. Both species and ecosystems may be adapted to either frequent or large disturbances (Grime, 1977). Harper (1977) argues that the evolution of attributes that enable a species to respond to a disturbance relate to the frequency of the disturbance events, relative to the life span and pattern of the life cycle (e.g., the aquatic insect species that have a terrestrial adult stage that overlays the normal periods of flooding) of the organism of concern. The size of the disturbance also influences the characteristics of species which inhabit a site. In some cases, a large disturbance event may even be the dominant force structuring the system, creating the template upon which subsequent ecological processes and interactions among species occur. Large crown fires in boreal forests, for example, create a mosaic of stands of varying ages that may persist for several centuries (Romme and Knight, 1982). Volcanic eruptions create a spatial structure for vegetation patterns that may endure for millenia.

Disturbances typically do not result in extensive areas of uniform impact (Turner et al., 1998). Rather, they create complex heterogeneous patterns across the landscape in which the disturbances have affected some locations but not others. For example, exposed ridges are more susceptible to damaging winds than sheltered coves (Boose et al., 1994), and even very large fires leave some stands unscathed because of wind shifts or natural fire breaks (Turner and Romme, 1994). The disturbance-generated mosaic has important influences on biotic structure and ecosystem processes. Understanding the nature of these landscape patterns and the factors controlling them is essential for understanding and predicting ecosystem dynamics and vegetation development, and for developing guidelines for natural resource management (Dale et al., 1998).

Natural disturbance regimes are not the equivalent of environmental *stressors* as the term is used in ecological risk assessment (see, e.g., EPA, 1998). However, human-induced changes to natural disturbance regimes (e.g., changes to fire regimes as a result of human fire-suppression activities; changes to flood regimes as a result of damming or channeling a river; changes in local weather patterns as a result of urbanization or forest removal) would be considered stressors to ecological systems. As with other parameters that are included in ecosystem condition reports, therefore, interpretation of data on disturbance variables requires comparison to “reference conditions” (in this case historical disturbance patterns) in order to detect changes that might indicate current or future change to ecological system function and sustainability (see Section 5).

a) **Frequency** of a disturbance refers to its return or recurrence interval. Some events, such as spring rains and snow melts that result in local flooding, occur annually or every few years and are not considered disturbances. On the other hand, rare and extreme flood events are generally considered to be those in which the area inundated, water depth, or water volume is beyond two standard deviations of the mean. For example, the 1993 floods in the midwestern U.S. were well beyond two standard deviations of the 30-yr averages for both depth and duration of summer flooding (Sparks and Spink, 1998). A frequency distribution of disturbance events (e.g., a 200-year flood) can be used to identify disturbances.

b) **Intensity** of a disturbance refers to the effects of the disturbance on the biota, rather than the energy released or force exerted by the disturbance, and it includes both the severity and magnitude of impact. Disturbance intensity is important in its own right; for example, hurricanes of the same spatial extent may have highly variable severities, which strongly influence ecological responses. The relationship between disturbance size and intensity is complex. The heterogeneity created by disturbances refers to the spatial distribution of disturbance intensities across the system. In the case of rivers, channel configuration is, on average, driven by intermediate level flow events; average annual flows being too small to create much physical alteration and very large events being rare (Wolman and Miller, 1960).

c) **Extent** is the spatial coverage of the disturbance event. Disturbance extent can be identified by statistical distributions (Turner and Dale, 1998), such as the mean and standard deviation. In landscapes affected by crown fires, a size distribution indicates that 1-3% of fire events account for 97-99% of the area burned (Bessie and Johnson, 1995). Thus, these few fire events are both infrequent and very extensive.

Alternatively, disturbance extent may be defined by perception of the event relative to a human scale or to the lifespan and attributes of the organisms in the ecosystem. For example, the 1980 eruption of Mount St. Helens was neither excessively large nor rare when considered in geologic time (Harris, 1986), but it was large when considered from the perspective of humans and the organisms that inhabited the area. It is important to recognize that "large" may well be a function of the relative size of the organisms. For example, a storm-induced disturbance patch of 35 to 100 m^2 in the intertidal zone may seem small from the human perspective, but it is large relative to the organisms that reside there. What is considered infrequent also must be considered relative to the lifespan of the affected organisms.

d) **Duration** refers to the temporal scale of the disturbance event, which may range from minutes/hours (e.g., earthquakes and some weather events) to days/weeks (e.g., some fire events) to months or years (e.g., some insect outbreaks). Long-running disturbances tend to have the greatest ecological impact. For example, droughts of several years can result in soil loss and local changes in species composition.

Table 8. Examples of Natural Disturbance Regimes

Example 8a: Fire Regime in a Forest	
Category	**Example Indicators and Measures**
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 8b: Flood Regime	
Category	**Example Indicators and Measures**
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 8c: Insect Infestation	
Category	**Example Endpoints and Measures**
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

4. INDICATORS OF STRESS – THE PARALLEL UNIVERSE

4.1 The Role of Stressor Indicators

In practice, reports about ecosystem condition often combine condition indicators with stressor indicators, at times indiscriminately. For the reasons outlined below, the SAB framework distinguishes between (natural) ecological condition indicators and (anthropogenic) stressor indicators, and the Essential Ecological Attributes and example indicators relate only to condition. This approach is consistent with the National Research Council's decision to "focus its recommendations on national indicators that inform about the status and trends in ecosystem extent, condition, and functioning, rather than focusing specifically on indicators of the stressors themselves" (NRC, 2000). The focus on condition indicators is also consistent with The Heinz Center's *Report on the State of the Nations's Ecosystems* (The Heinz Center, 1999; in press).

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 used by the Organisation for Economic Cooperation and Development (OECD, 1998), distinguishes pressures (i.e., stressors) from state (i.e., condition) variables, as does the Harwell et al. (1999) proposal for a report card framework. The ecological assessment and reporting scheme for the Great Lakes (Environment Canada and U.S. Environmental Protection Agency, 1999) also includes both pressure and state indicators. Ultimately, the decision on whether (and how) to include stressors in an ecological condition assessment may depend primarily on the purpose of the assessment. Because the framework proposed here may be used in a scheme that also includes the "parallel universe" of anthropogenic stressors, this section discusses how stressor variables relate to the framework of EEAs, categories, and subcategories presented in Section 3.

One category of environmental assessments that often will include information on both condition and stressor measures is that of *ecological risk assessment*. Although risk assessments are generally focused on understanding the effects of anthropogenic stressors on ecological systems, the framework proposed here may provide a useful reference scheme for such assessments. Specifically, the array of ecological attributes presented in Table 1 may be used as a checklist to help formulate conceptual models related to ecosystem structure and function, and as a checklist to identify the assessment endpoints that should be evaluated to detect adverse effects.

> "***Ecological risk assessment*** is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors... Changes often considered undesirable are those that alter important structural or functional characteristics or components of ecosystems." (EPA, 1992)

4.2 Rationale for Separating Condition and Stressor Assessments

Distinguishing ecological condition indicators from anthropogenic stressor indicators has a number of advantages. First, it more clearly differentiates natural variations from human-induced variations. This distinction facilitates environmental remediation and natural resource management in those situations where managers do not intend to alter natural variations, including those caused by natural disturbance regimes. Increasingly, society has recognized that altering natural disturbance regimes (e.g., restricting the frequency of forest fires or altering the course of rivers) may have serious long-term adverse effects.

Second, addressing anthropogenic stressors separately enables more systematic assessment of the relationships between these stressors and ecosystem impacts. Anthropogenic stressors may have both direct and indirect effects upon one or more Essential Ecological Attributes. Assessing the complete array of condition indicators, as well as stressor indicators, can aid the analysis of the causal mechanisms underlying compromised ecosystem conditions. In addition, as Harwell et al. (1999) recognized, stressors often can be characterized more easily and rapidly than their effects because there may be a significant lag time between the stressor and the effect.

A third reason for the distinction between indicators of condition and of stress is to encourage indicator selection criteria to be based upon fundamental environmental attributes and processes, rather than current data availability. Reports on ecosystem condition often focus primarily or exclusively on anthropogenic stressors because data of this type (e.g., on emissions, criteria exceedances, or incidents) already are collected through conventional regulatory processes. This focus on select data creates potential for overlooking important ecosystem characteristics and prioritizing environmental risks and protection needs inappropriately.

Last, distinguishing condition and stressor indicators can be helpful in allocating management responsibilities among public and private institutions, depending upon their charters and regulatory domains. An assessment and reporting framework that separates, yet clearly links, stressor and condition measures may lead to more comprehensive, cross-agency and cross-media coordination of environmental management functions.

4.3 The Relationship Between Ecological Condition and Stressor Indicators

Figure 4 illustrates the relationship between common anthropogenic stressors and one or more of the Essential Ecological Attributes. Stressors were qualitatively identified with one or more of the EEAs on the basis of how their effects are mediated, reflecting the multiple mechanisms by which stressors may affect different aspects of ecological systems. The Panel concluded that each EEA (and each category, each subcategory, and many indicators) may be affected by more than one stressor. Conversely, each stressor may directly (and/or indirectly) affect more than one EEA (and category and subcategory). For example, habitat conversion may

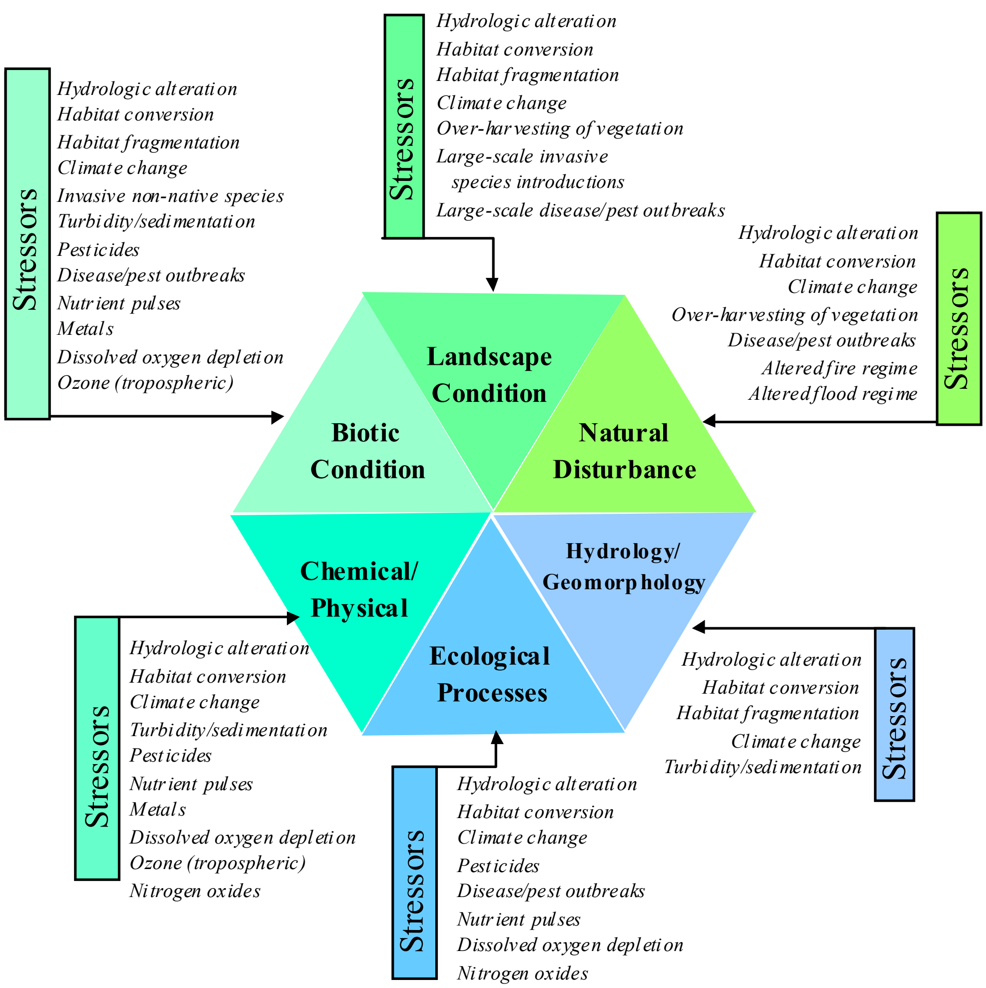

Figure 4. Sample stressors and the Essential Ecological Attributes they affect.

alter groundwater and surface flows, and the change in groundwater levels may then alter the intensity and extent of fires. In short, a one-to-one correlation between a particular attribute and a single stressor may occur, but often may be a misleading oversimplification.

In general, stressors fall into one of two categories: a) unnatural and adverse perturbations of ecological attributes; or b) the introduction of a foreign agent -- physical, chemical or biological -- into an ecosystem at a level that interferes with essential ecological processes.

In the first category, the stressor indicator is a significant and adverse departure "beyond reference conditions" assumed for the ecological indicator. Thus, it is important to define the natural range of variability in environmental conditions, to which ecological systems presumably are adapted, as distinguished from extreme or atypical variations induced by human activities. (See Section 5 for discussion of reference conditions.) In the case of chemical or physical attributes, condition measures may have the same units as measures used to report on anthropogenic stressors. For example, dissolved oxygen and pH are measures of water chemistry that are useful for describing both pristine and impacted surface waters. Natural variation in these environmental parameters defines in part the types of organisms adapted to those waters. On the other hand, anthropogenic stressors (e.g., high organic loadings or acid deposition) may introduce excursions and deviations in dissolved oxygen and pH beyond natural ranges and cycles, thus altering the resident biological communities.

Stressors in the second category may require a different set of measures (e.g., concentration of a xenobiotic chemical; infestation of an introduced pest species) than those chosen as the ecological indicator or measure. A comparison of condition indicators and stressor indicators for hydrology and geomorphology characteristics, for example, illustrates this point (see Table 9). Both Table 9 and Figure 4 tend to underplay the fact that most stressors do not have a one-to-one relationship with ecological condition attributes. Ecological risk assessments use conceptual models to relate each major stressor to its potential effects on multiple condition parameters. Conversely, assessment of ecological condition shows the effects of multiple stressors and highlights unforeseen effects.

The distinction between condition and stressor indicators is to some extent a subjective judgment. The Heinz Center report (in press), for example, includes concentrations of xenobiotic chemicals as condition indicators. In other cases, a measure may legitimately be considered both a condition and stressor measure; for example, tissue burdens of pesticides may be a condition measure (for the organism) and a stressor measure (for the organism's consumers). The decision to report levels of xenobiotic chemicals in the environment as indicators of condition (or even as indicators of stress) may be controversial, however, because of the difficulty in determining what levels of such chemicals may be associated with environmental effects. For example, recent monitoring studies have reported low concentrations of many xenobiotic compounds (e.g., pharmaceutical chemicals, personal care products, and agrochemicals) in multiple environmental media (Kolpin et al., 2002), but the implications of these findings for environmental condition are unclear. After considerable debate, the Panel concluded that chemical concentrations in the environment logically could be reported as either condition or stressor measures, depending on whether and how the chemical impacts the ecological system. In some cases, it may be necessary or appropriate to report on levels of xenobiotic chemicals as indicators of prior exposure or potential vulnerability. In other cases, xenobiotic chemicals may be listed as condition indicators in order to reflect their dominant effect or control on the system. Alternatively, xenobiotic chemicals (or introduced species) may be reported as stressor indicators when they are associated with adverse ecological effects. In the latter case, an interpretive guideline (e.g., a water quality criterion, a soil screening level, or an effects threshold in a bioassay) may be required to establish causality or severity. Finally, the Panel notes that, in highly managed or modified ecosystems, stressors may be introduced intentionally to maintain the ecosystem in its desired state (e.g., herbicides in agricultural plots, introduced species of game fish in a lake). In these cases, the definition of stressor vs. condition indicators is highly subjective and will be determined by the context and the authors' judgment.

Table 9. Comparison of Condition Indicators and Stressor Indicators: Examples for Hydrology and Geomorphology

Essential Ecosystem Attribute	**Category**	**Subcategory**	**Example Ecological Condition Indicators**	**Example Stressor Indicators**
Hydrology and Geomorphology	Surface and Groundwater Flows	pattern of surface flows	flow magnitude and variability, including frequency, duration, timing, and rate of change	number of dams per 100 miles; percent of flows diverted; stream bed scouring due to extreme runoff
		pattern of ground water flows	groundwater accretion to surface waters; net recharge or withdrawals	amount of impervious surface; number of irrigation wells
	Dynamic Structural Characteristics	channel morphology; shoreline characteristics	mean width of meander corridor; length of natural shoreline	number of river miles channelized or rip-rapped; extent of hardened lake shoreline
	Sediment and Material Transport	sediment supply and movement	sediment deposition; sediment residence time and flushing	amount of soil erosion from agricultural fields

5. APPLYING THE FRAMEWORK

5.1 Getting Started

Although the framework and the hierarchical list of Essential Ecological Attributes presented here are straightforward, we recommend that an initial design process be used to define how the framework will be tailored to fit the program at hand. The final product of the design process should not only describe the assessment and reporting scheme, but also record the decision tree and professional judgments used to develop it.

Substantial information already is available from other sources regarding the development of goals and objectives, the selection of indicators, and the design of monitoring programs (see, e.g., Cairns et al., 1993; EPA, 1998; NRC, 2000; McDaniels, 2000; Dale and Beyeler, 2001). Accordingly, this section will focus on the use of the EEA list to either plan an assessment of the condition of an ecological system or report the results of such an assessment.

5.2 Using the Hierarchical List of Attributes

The purpose of the attribute list (Table 1) is to provide organizational structure for the process of selecting ecological system characteristics for assessment and/or reporting. The first step in this process is to define the context of the ecological condition assessment. Relevant considerations include the purpose of the assessment (e.g., ecosystem management, informing general land-use decisions, public information, feedback regarding the success of environmental protection efforts), and whether the assessment is a one-time, synoptic study, a longer term evaluation of trends, or both. The level of resources available for the assessment and the existence of data from other studies or ongoing monitoring programs also will affect tailoring of the framework. However, during this preliminary program design, critical data needs for condition and stressor assessment should be the principal focus. Additionally, the decision should be made either to limit the assessment to ecological system condition (as did the NRC and Heinz Center efforts) or to include a parallel assessment of stressors (as did the Great Lakes State of the Lakes Ecosystem Conference [SOLEC] and Chesapeake Bay reports).

Preliminary design work also will include the definition of the geographic scope and an inventory of the type(s) of ecosystems and habitat types that will be included. For assessments that cover large geographic areas and incorporate many ecological regions, design work may require the development of a hierarchical typology or classification scheme (see, e.g., Levy et al, in press) that divides the ecological system into workable subunits for analysis.

Some characteristics of ecological systems–e.g., topography, geology, and dominant weather patterns–do not change except on very long (e.g., geologic) time scales. These relatively stable attributes generally have not been included in the description of the EEAs, and yet are relevant to the interpretation of assessment results. These stable attributes also may be summarized as contextual background.

Once the purpose and scope of the condition assessment have been determined, the hierarchical list of Essential Ecological Attributes can be used to guide the selection of characteristics that will be assessed. To determine which characteristics are appropriate for the assessment, the Panel recommends beginning with a rebuttable presumption that all of the entries in Table 1 will be included. A "thought experiment" can then be performed to eliminate subcategories and categories that are not relevant to the ecological system or to the purpose of the assessment. When resources (i.e., time, personnel, funding) 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 included, rather than eliminate an entire EEA. When exceptions are made, consideration may be given to reinserting the category or EEA during ongoing adaptive management.

In short, the list of characteristics and indicators to be included in an assessment ultimately will be defined by the attributes of the system itself and by the contextual factors mentioned above. To the extent feasible within these constraints, however, the Panel recommends using the elements of the hierarchy presented in Table 1 so that the assessment will incorporate the array of components required to characterize ecological condition.

Part of the utility of the hierarchical EEA list is that an assessment can be planned even in the absence of a conceptual ecological model of the system. It is preferable, however, to develop a conceptual model that displays the interactions among the characteristics (subcategories, categories, and/or EEAs) chosen for assessment. The conceptual model, which will be used to inform the initial selection of characteristics to be assessed, should reflect the latest scientific understanding of the inherent properties (i.e., patterns and processes) of that ecosystem type, rather than focusing on management objectives or stressor response. The conceptual model and the hierarchical list of EEAs and subsidiary characteristics are complementary tools that help assure that the assessment will include all characteristics that define the ecological system.

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 components selected should be sufficient to address any goals and objectives that have been developed for management of the ecosystem. Similarly, components of the list should be sufficient to address questions of known public interest (such as the preservation of particular species or the sustainability of patches of old-growth forest). If the list falls short, then additional subcategories and indicators may be added. Development of a conceptual model that graphically illustrates the relationship between various management objectives (or public interest issues) and the elements of the EEA hierarchy will be useful during this design phase and will help non-scientists understand the relationships between the ecosystem components and the objectives.

An additional check of the preliminary list of EEAs, categories, and subcategories to be included in the assessment should assure that the list addresses the structure, composition, and function of the system at all relevant hierarchical levels. (See Appendix B for additional detail.) It also is advisable to survey the temporal characteristics of the list, to assure that some of the indicators will respond in a reasonably short time frame and some will represent long-term dynamics. Some of the EEAs will exhibit change over several time scales (e.g., annual, decadal), but for each category there is generally a time scale over which to observe both natural variation and changes outside the normal range.

Following the selection of indicators and measures, an iterative review of the attribute list generally should be undertaken. At this point, it may be possible to trim the list of attributes and/or indicators (based on their potential to respond to and represent changes in the focus system and their ability to collectively represent the system) to eliminate redundancies and create a parsimonious set.

The final product of this portion of the design process would include:

a) relevant information about the context of the assessment;
b) the hierarchical list of attributes (and ideally, indicators) selected for the assessment;
c) the rationale behind these selections and the underlying conceptual model;
d) the rationale for omitting other attributes or indicators that were considered; and
e) the proposed process for collapsing the indicator data into subcategories, categories, and EEAs for reporting.

In addition to this detailed technical record, a summary of the design process should be included in the public report.

5.3 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.

One major purpose of this framework and EEA list (Table 1) is to help avoid common reporting problems. First, 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. Faced with this problem, many report authors select a small subset of indicators they judge to be important. Although their reasoning may be sound (e.g., select indicators that are of interest and understandable to the public), the resulting report often appears to be a disjointed collection of facts that does not adequately characterize ecological condition or effectively address other goals developed by society for ecosystem management. Second, many report authors confine their reporting to information that is readily available. Yet most easily accessible information (e.g., water quality data regarding chemical contaminants) is related to past problems and is only part of the information required to predict future problems or manage the ecosystem. This approach also reinforces a somewhat circular public policy: people care about what they learn about via reports; and reports contain information that the authors think people care about. Information that might lead to more informed decisions --wherein protective or corrective actions are targeted at the most important problems-- may be left out of this circular loop.

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. 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 is also 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, such as the Chesapeake Bay report card (Chesapeake Bay Program, 2001), 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; the presentation, however, likely would benefit from conversion into understandable 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, Natural 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 1 – involves both policy decisions and 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. The procedure does not have to be complicated; in many cases, simple algorithms or qualitative ranks can be used. It is important to record why particular aggregation methods are chosen and then explain clearly any value judgments or applications of expert opinion that affect the aggregation methods or weighting schemes.

5.4 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 (quantitatively or qualitatively) for aggregation. This normalization procedure allows various indicators or indices to be collapsed into a single aggregated result. Reference conditions should be established for each ecoregion, resource type, or other ecological unit addressed in the assessment. In this way, normalized results for the same characteristic may be compared to results from different ecoregions. (For example, biotic condition in one area can be compared to biotic condition in another area, even though the underlying measurements or indicator values are different in the two locations.)

Often, environmental conditions are defined along a spectrum – with conditions at one end representing an ecosystem with a high degree of integrity and those at the other end representing an ecosystem that is highly degraded. The spectrum defines a scale for normalizing and interpreting measured values for indicators. This is the general approach used to develop several common indices of biotic integrity. First, a list of species population, community, habitat, or landscape characteristics is assembled that is thought to represent ecological state. Second, an evaluation scale for normalizing each measured characteristic is developed (generally using qualitative assessments such as "excellent", "good", "fair", or "poor"). Third, the information for the multiple metrics is combined into a single index or score. Some examples of this approach are the diversity indices (e.g., Cao et al., 1996), indices of biotic integrity (e.g., Karr and Chu, 1999), benthic indices of biotic integrity (e.g., Engle et al., 1994; Weisberg et al., 1997), and functional group analysis (e.g., Merritt and Cummins, 1996; Waters, 2000). The Agency's Rapid Bioassessment Protocols (Barbour et al., 1999), which address biological and geomorphological characteristics of rivers, also employ this approach.

Reference conditions that attempt to define a "healthy" ecological system are often derived from either the conditions that existed prior to anthropogenic disturbance or conditions in a relatively undisturbed but comparable system in the ecoregion. Alternatively, reference conditions can be inferred from a combination of historical data, a composite of best remaining regional conditions, and professional judgment. In previous reviews, the SAB has recommended that hypothetical reference conditions be established (using information from actual sites, historical data, empirical models, and expert opinion), rather than actual reference locations that may exhibit changing environmental conditions over time (EPA Science Advisory Board, 1997a).

Ecosystems are dynamic and variable, and each set of reference conditions should address this fact. The "historic range of variability" of ecosystem attributes characterizes the variation and distribution of ecological conditions occurring in the past. The term "historic range of variability" often refers to natural conditions occurring over a period of centuries; in this context, it may represent conditions of high ecological integrity. If the historic range of variability of ecological conditions includes anthropogenic disturbance, then it would simply represent a long-term baseline. Such a baseline could still be used to develop a scale for interpreting measured values of indicators; however, the users should be aware of the anthropogenic disturbances that are included in the long-term record.

The definition of reference conditions that represent a high degree of ecological integrity is largely a scientific endeavor. Selection of reference sites, for example, should be a science-based activity. In contrast, development of benchmarks that serve as goals for ecosystem management or restoration will be a combined effort of scientists, ecosystem managers, and the public. Management or regulatory benchmarks should be developed based on scientific understanding of the environmental state likely to be achievable under current or proposed stressor regimes, but ultimately will reflect societal decisions about desired uses of the resource.

6. EXAMPLE APPLICATIONS OF THE REPORTING FRAMEWORK

6.1 Introduction

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 EPA Office of Research and Development program designed to assess current condition and long-term trends of ecological systems; a USDA Forest Service program designed to assess forest condition nationwide; an EPA Office of Water program designed to convey information about watershed health to the public; and a joint EPA-state reporting program designed to track progress toward meeting environmental goals. At public meetings in July 1998 and September 2000, the Panel received briefings from representatives of the selected programs. The following case examples include brief program descriptions (based on briefings and materials provided to the members of the Panel and on prior SAB reviews) and a discussion of how the proposed framework might be applied to the program. The discussion of the example programs does not constitute a formal SAB review of the programs. In conducting these analyses, the Panel considered the following questions:

a) Does the program include measures that do not fit within the categories or subcategories of the proposed SAB framework? If so, can these measures be included?

b) Has the program missed something that is included in the proposed SAB framework?

c) Does the EEA hierarchy provide a sensible way to organize the program's indicators?

d) Would the proposed SAB framework and EEA hierarchy make it easier to convey the importance and context of the program to others (either within or outside the Agency)?

e) Does the Panel have any other general insights or recommendations for the program with regard to reporting on ecological condition?

6.2 EMAP-West

6.2.1 Background

The Agency's Environmental Monitoring and Assessment Program (EMAP) was developed to provide a description of the current status and longer term trends of ecological attributes in terrestrial and aquatic systems nationwide. An associated purpose of the program is to track changes in ecological health tied to environmental legislation, including the Clean Water Act. EMAP data also may be used to prospectively characterize risks posed by large-scale environmental stresses, such as acid deposition and climate change.

The EMAP is distinguished by its use of a spatially tessellated statistical sampling design that provides for random sampling of the nation's ecological resources. EMAP includes both ecological condition measures and stressor measures.

One aspect of the EMAP is a series of regional-scale demonstration projects such as the Mid-Atlantic Integrated Assessment (MAIA), which collected and integrated environmental information for a region from southern New York to northeastern North Carolina (e.g., Jones et al., 1997). A second regional pilot, referred to as EMAP-West, was begun in 1999 to develop baseline descriptions for aquatic resources in western landscapes, streams, and estuaries in a twelve-state region (EPA, 2001). EMAP-West will be implemented in partnership with a variety of state, tribal, and federal agencies (e.g., NOAA and USGS). Data and information collected during the EMAP-West pilot will be used to support environmental assessments at local, state, and regional levels; establish a long-term archive of data in STORET; provide data for general public use; and help develop data systems that then can be maintained by local and state groups. The Panel chose EMAP-West as its first case study for application of the proposed framework.

The EMAP-West contains three components: Coastal Waters, Surface Waters, and Landscapes. The indicators specified for each of these components are discussed below and summarized in Table 10.

Coastal Waters: The Western Pilot for estuaries will complete a statistically based, unbiased, and representative sampling of more than 700 sites in Washington, Oregon, and California. Particularly intensive sampling will occur in the Northern Rivers area in California and the Tillamook Bay, Oregon. The Western estuaries EMAP will use the sampled systems as biological integrators of environmental stress, provide for aggregation of data across local, state and regional levels, and generate cost-effective information for describing ecological condition in these estuaries. Selected estuarine indicators include a description of the benthic community assemblage, fish assemblage, measures of fish pathologies, fish tissue contamination, mapping of submerged aquatic vegetation, sediment measures (e.g., grain size, total organic carbon, chemical characteristics, and sediment toxicity), and water column parameters (e.g., nutrients, temperature, salinity, depth, dissolved oxygen, pH, and chlorophyll).

Surface Waters: The stream study entails a statistically based sampling of 900 locations in 12 states, including 18 ecologically distinct western ecoregions. Fifteen percent of the locations for both streams and rivers will be revisited in the sampling effort. The objective of the study is to develop criteria for ecological reference sites to allow comparisons of ecosystem condition. The EMAP surface water indicators to be characterized for each site include descriptions of fish assemblage, fish tissue contamination, periphyton community structure, macroinvertebrate assemblage, physical habitat descriptors (e.g., riparian zone, woody debris, canopy cover, gradient), and physico-chemical parameters (e.g., nutrients, temperature, alkalinity, dissolved oxygen, and heavy metal concentrations).

Landscapes: The EMAP-West Landscape Study will focus on watershed scale indicators, riparian descriptors, and biophysical measures. The watershed indicators include a human use index, a measure of agriculture on steep slopes, a natural cover type index, human population density, and the number of roads that cross streams. The percentage of stream miles with different types of land cover will be used as an indicator of riparian condition. Average watershed slope and the Palmer Drought Severity Index have been selected as representative biophysical indicators.

6.2.2 Application of the SAB Framework

One direct way to evaluate the potential application of the SAB reporting framework to the EMAP-West pilot is to compare EMAP-West's indicators with the EEA hierarchy (Table 1) that summarizes the attributes comprising ecological condition. As Table 10 shows, all of the condition measures included in the EMAP-West pilot can be incorporated into the SAB framework. On the other hand, EMAP-West will collect data that pertain to several, but certainly not all, of the categories contained in the SAB's proposed reporting framework.

The landscape component of EMAP-West includes information about natural land cover, but focuses primarily on inferential measures of human impacts (i.e., stressor measures) and drought potential. While the inclusion of these watershed-scale indicators is an improvement from earlier EMAP studies, it is not clear to the Panel how this information might be used to evaluate landscape pattern and structure, landscape composition, or the remaining extent of different types of habitats. Conversely, however, EMAP-West highlights the fact that the Landscape Condition EEA should be interpreted to include human-dominated land uses such as urban and intensively managed agricultural areas.

The data collected for streams and rivers incorporates most of the categories included in the Physical/Chemical Characteristics and Biotic Condition EEAs, as well as important elements of the Hydrology and Geomorphology EEA. Genetic diversity, however, is a notable omission from the biotic condition assessment in light of the need to manage endangered salmon stocks. Similarly, ecological processes and disturbance regimes are not covered. In a region where wildfires, droughts, floods, and even volcanic eruptions shape the ecology, the omission of disturbance regimes will make it more difficult to interpret data and define reference conditions.

In this example, therefore, it appears that use of the EEA hierarchy (Table 1) as a checklist provides valuable insight that might be used to expand the program and/or aid the interpretation of the results. In addition, the EEA hierarchy could be used as a way to organize EMAP-West data into data systems for local groups and provide a structure within which to incorporate information from other monitoring programs to fill gaps in the EMAP-West indicator list. Even when these additional data are not based on the EMAP's statistical sampling design, they can provide useful input to the anticipated environmental assessments.

In the Panel's opinion, EMAP-West is not atypical in its omission of ecological processes. This is one reason that ecological processes are highlighted as a separate EEA in the proposed framework. EMAP-West could incorporate ecological process measurements by expanding its GIS-based spot sampling design to a tiered system, similar to that used by the Forest Health Monitoring Program (See Section 6.3). In a tiered approach, intensive process-based studies of a small number of representative areas, plus integrated measures for whole ecosystems, are coupled with the widespread randomized spot sampling. Long-term intensive study of selected plots provides process information that helps explain the patterns measured across the rest of the monitoring sites.

The EMAP-West estuaries study emphasizes physical and chemical attributes of the water column and sediments, coupled with measures of fish (i.e., representative organism) condition. Other aspects of biotic condition include community composition and the physical habitat structure provided by submerged aquatic vegetation. Although the sampling design reflects one of the pilot's objectives – to correlate certain stressors with biological characteristics – comparison with the SAB framework shows that critical ecosystem characteristics that influence biotic condition have been omitted. The missing characteristics may be candidates for later addition, particularly to the extent that they help explain correlations (or lack thereof) between chemical or physical data and biotic condition. As mentioned above for the streams and rivers section of the pilot, the EEA hierarchy could provide a classification scheme for organizing data from other monitoring programs along with EMAP data to provide a more comprehensive assessment of estuarine condition.

In sum, it appears that the EEA hierarchy does provide a sensible way to organize EMAP-West's indicators in order to determine what elements have been omitted from the pilot. In the Panel's view, the ability to highlight missing elements such as genetic characteristics (in view of the endangered salmon controversies) and disturbance regimes (in view of the importance of fire, drought, and volcanic eruptions in the area) is a valuable asset. The EEA hierarchy also provides an organizational scheme for integrating the EMAP-West data with data from other programs; presenting the combined information to the local, state, and regional groups who will use the EMAP results; and helping to explain how each of the indicators is relevant to ecological condition. In addition, it seems likely that using the EEA hierarchy as an organizing scheme could help the Office of Research and Development highlight the utility of EMAP to other parts of the Agency.

Table 10. EMAP-West Indicators Organized Using the SAB Framework

SAB Reporting Categories and Subcategories			EMAP Western Pilot: Coastal (c) and Surface Waters (Rivers and Streams) (s) and Landscapes (l) (EPA, 2001)	
			Condition Measures	**Stressor (or Stressor Surrogate) Measures**
Landscape Condition				
	Extent of ecological system/habitat types		submerged aquatic vegetation (SAV) abundance (c)	
	Landscape Composition		occurrence of submerged aquatic vegetation (c), occurrence of macroalgae (c), riparian vegetation (s), average slope of watershed	
	Landscape Pattern/Structure		natural cover type index (l)	human use index (l); agriculture on steep slopes (l); population density (l); roads crossing streams (l); % of stream miles with different types of land cover (l)
Biotic Condition				
	Ecosystems and Communities			
		Community Extent		
		Community Composition	benthic community assemblage (c), stream macroinvertebrate assemblages, fish community assemblage (c, s), periphyton assemblage (s), phytoplankton (rivers)	
		Trophic Structure		
		Community Dynamics		
		Physical Structure		
	Species and Populations			
		Population Size		
		Genetic Diversity		
		Population Structure		
		Population Dynamics		
		Habitat Suitability (focal species)	submerged vegetation (c), riparian habitat/land use (s)	
	Organism Condition			
		Physiological Status		
		Symptoms of Disease or Trauma	fish pathologies (c)	
		Signs of Disease	fish parasites (c), fish tissue residues of metals and organic contaminants (c), Hg in fish tissues (s)*, persistent organic contaminants in fish tissue (s)*	fecal coliform (surrogate indicator of microbial pathogens)(c)
Chemical and Physical Characteristics (Water, Air, Soil, Sediment)				

	Nutrient Concentrations		nutrients (c)	
		Nitrogen	total N, nitrate, ammonium (s)	
		Phosphorus	total P (s)	
		Other Nutrients	silica (s)	
	Trace Inorganic and Organic Chemicals			sediment toxicity (c)
		Metals	metals in sediments (c)	
		Other Trace Elements		
		Organic Compounds	organic contaminants in sediments (c)	
	Other Chemical Parameters			
		pH	pH (s, c)	
		Dissolved Oxygen/Redox Potential	dissolved oxygen (c)	
		Salinity	salinity (c)	
		Organic Matter	sediment total organic carbon (c), dissolved organic carbon (c, s)	
		Other	cations and anions (s), dissolved inorganic carbon (s), acid neutralizing capacity (s)	
	Physical Parameters			
		soil/sediment	substrate/grain size (c, s), silt/clay percent (c)	
		water/air	temperature (c, s), water depth (c), turbidity and suspended sediments (c, s)	
Ecological Processes				
	Energy Flow			
		Primary Production	chlorophyll (c), algal pigment abundance (c)	
		Net Ecosystem Production		
		Growth Efficiency		
	Material Flow			
		Organic Carbon Cycling	microbial abundance (c)	
		N and P Cycling		
		Other Nutrient Cycling		
Hydrology and Geomorphology				
	Surface and Groundwater Flows			
		Pattern of Surface Flows	river discharge (c), stream discharge (s)	
		Hydrodynamics		
		Pattern of Groundwater Flows		
		Salinity Patterns		
		Water Storage		
	Dynamic Structural Characteristics			
		Channel/Shoreline Morphology and Complexity	channel morphology (s)	

		Extent and Distribution of Connected Floodplain		
		Aquatic Physical Habitat Complexity	submerged vegetation (c), fish cover (s), large woody debris (s)	
	Sediment and Material Transport			
		Sediment Supply and Movement		
		Particle Size Distribution Patterns		
		Other Material Flux		
Natural Disturbance Regimes				
	Frequency			
	Intensity		Palmer drought severity index (l)	
	Extent			
	Duration			

*If additional funds become available (EPA, 2001)

6.3 Forest Health Monitoring Program

6.3.1 Background

The Forest Health Monitoring (FHM) Program is a monitoring and assessment program of the USDA Forest Service initiated in 1991 and currently operating in 48 states with an annual budget of approximately $9 million. At inception in 1991, the FHM was a joint effort of the EPA EMAP and the Forest Service, and the program uses the EMAP probability based sampling design. (Recently, the FHM program was integrated with the Forest Inventory and Analysis (FIA) program of the Forest Service; FHM ground plots are now Phase 3 of the FIA plot network.) The objectives of the FHM program are to evaluate the status and trends in forest condition and health across the U.S., including both public and private forested lands. The program is a tiered effort with a) a national status and trends detection component; b) an intensive evaluation component for areas where serious problems are detected; and c) an intensive site monitoring component co-located with National Science Foundation Long Term Ecological Research (LTER) sites. The latter component of the program allows hypothesis testing via field experimentation and is a critical component of the effort.

The FHM program utilizes the Santiago Declaration Criteria and Indicators for Conservation and Sustainable Management of Temperate and Boreal Forests (www.fs.fed.us/land/sustain_dev/sd/sfmsd.htm) as a framework for sustainability assessment and reporting. Forest health indicators are analyzed and reported by the ecoregion section as defined by Bailey (1995).

The FHM provides ready public access to both summary information and quality-assured data through its web site (www.na.fs.fed.us/spfo/fhm/index.htm), which is an important aspect of any program intended to assess ecological condition. Because the program is spatially explicit, map products are being developed as a powerful and effective means of summarizing results in a way that is readily understood by both the scientific community and the public. In addition to maps, tabular summary data are provided by ecoregion and subunits within these landscape units.

The focus of the FHM program is to derive measures of forest "sustainability" and the effects of stressors (e.g., exotic species, management, climate, air pollution, extreme natural events). Sustainability is defined in terms of productivity, carbon cycling, water conservation, soil conservation, diversity, and forest vitality. Because of fiscal constraints, the FHM program has focused almost exclusively on aboveground tree metrics, primarily symptomology (e.g., crown density, percent crown dieback) along with species composition, stand structure, and productivity. In recent years, however, other indicators of forest condition have been implemented, including lichen assemblages and soil properties. Most recently, there have been increased efforts to utilize GIS and remote sensing capabilities in spatial extrapolation and interpretation of data.

The FHM program currently is monitoring a variety of indicators including symptom indicators (mortality, dieback, tree crown transparency, ozone damage on foliage), species composition (trees, lichens, exotic species presence), and process indicators (productivity). The program also is making efforts to provide cost-effective linkages with other ecological and environmental data, such as networks that define precipitation chemistry (i.e., acid deposition), air quality (e.g., ozone levels), and meteorology (e.g., precipitation and temperature).

6.3.2 Application of the SAB Framework

Despite its initial focus on stressors, the FHM metrics map directly to the EEA hierarchy. All of the condition measures of the FHM program fit within the proposed EEA categories (Table 11). Conversely, the FHM measures provide fairly complete coverage of the EEA hierarchy; the exceptions are hydrology and geomorphology, and information about disturbance regimes (which is inferred by evidence of tree damage rather than being characterized explicitly, as proposed by the SAB). The fact that the FHM measures cover many of the condition categories in the proposed SAB framework is a testament to the recognition by the U.S. Forest Service that maintenance of forest ecosystem integrity is an important component of forest management, whether on public or private lands.

The tiered evaluation approach used by the FHM program could serve as a template for establishing a hierarchy of measurements within the Ecological Processes EEA. The hierarchy would distinguish indicators appropriate at the whole-ecosystem scale from indicators that could be used to more intensively monitor smaller scale plots (e.g., to monitor energy cycling). Use of the SAB reporting framework as a checklist also could be useful to the FHM program over time to guide decisions on additions or deletions of metrics; for example, the SAB framework emphasizes the need to continue developing forest ecosystem-level assessments (rather than just mensurational data such as tree size and wood volume) and process measurements.

The Panel also hopes that use of the EEA hierarchy to describe the FHM indicators could provide a tool for combining data from the FHM program with data from programs in other agencies. By providing a single organizational scheme that can be used for different ecosystem types and geographic scales, the SAB framework can be used to integrate information from a variety of different agencies, which then can be used for a variety of purposes.

Within the Forest Service, for example, information routinely collected at FIA plots (including slope, aspect, soil depth, soil drainage characteristics, and amount and severity of tree injury) and FIA landscape level measures (e.g., the extent of forest types and forest fragmentation) may be integrated and reported with FHM data to provide a more comprehensive assessment of forest condition. The SAB framework also provides a means of relating FHM data to data on rainfall, climate, and disturbances (e.g., insects, fire, ice or wind storms) that are collected by other programs and entities. For example, annual aerial and ground surveys conducted by FHM partners map and quantify tree mortality and damage caused by forest insects, pathogens, and extreme weather events.

Table 11. FHM Indicators Organized Using the SAB Framework

SAB Reporting Categories and Subcategories			Forest Health Monitoring Program and Forest Inventory and Analysis (FIA) Parameters[1]	
			Condition Measures	**Stressor (or Stressor Surrogate) Measures**
Landscape Condition				
	Extent of ecological system/habitat types		remote sensing of extent of forest/non-forest land uses (FIA)	
	Landscape Composition		forest types (FIA)	
	Landscape Pattern/Structure		forest fragmentation (FIA)	urbanization, rates of land use change, distance to roads (FIA)
Biotic Condition				
	Ecosystems and Communities			
		Community Extent		
		Community Composition	tree community composition, lichen community composition, presence of exotics	presence of exotics, lichen community composition (bioindicator of exposure to N– and S-based air pollutants)
		Trophic Structure		
		Community Dynamics		
		Physical Structure	stand structure, down woody debris, slope	
	Species and Populations			
		Population Size		
		Genetic Diversity		
		Population Structure	stand age	
		Population Dynamics	regeneration; growth rates	
		Habitat Suitability		
	Organism Condition			
		Physiological Status	growth rates, tree size class	
		Symptoms of Disease or Trauma	tree mortality, dieback, tree crown transparency, ozone-damaged foliage	evidence of damage (from insects, disease, fire, animals, weather, or logging) (FIA)
		Signs of Disease		

Chemical and Physical Characteristics (Water, Air, Soil, Sediment): SOIL				
	Nutrient Concentrations			
		Nitrogen	total soil nitrogen	
		Phosphorus	plant-available (extractable) phosphorus	
		Other Nutrients	exchangeable cations (e.g., Ca, Mg, and K)	
	Trace Inorganic and Organic Chemicals			
		Metals	extractable metals	
		Other Trace Elements		
		Organic Compounds		
	Other Chemical Parameters			
		pH	soil pH	
		Dissolved oxygen/Redox Potential		
		Salinity	carbonates	
		Organic Matter	soil organic matter content, total organic carbon, forest floor measures	
		Other		
	Physical Parameters			
		soil/sediment	soil texture, depth of litter, percentage of soil compaction	
		water/air		
Ecological Processes				
	Energy Flow			
		Primary Production	timber/wood volume (calculated from tree height and diameter measures) (FIA)	
		Net Ecosystem Production		
		Growth Efficiency		
	Material Flow			
		Organic Carbon Cycling	carbon storage in tree biomass	
		N and P 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 and complexity		
		extent and distribution of connected floodplain		
		aquatic physical habitat complexity		
	Sediment and Material Transport			
		sediment supply and movement		
		particle size distribution patterns		
		other material flux		
Natural Disturbance Regimes				
	Frequency			
	Intensity		(for insects, pathogens and extreme weather events: inferred from annual surveys of tree mortality and damage)	
	Extent			
	Duration			
[1]The table includes only a subset of the FIA parameters that relate closely to forest condition.				

6.4 Index of Watershed Indicators

6.4.1 Background

The Index of Watershed Indicators (IWI), developed by the Agency's Office of Water, is advertised as a snapshot of the "health of aquatic resources." The IWI provides a website (www.epa.gov/iwi) that allows members of the general public to obtain information about any watershed. Its easy accessibility and understandable graphic format (watershed and national maps) make it a powerful potential tool for public education about watershed condition. The IWI was originally conceived as a method for highlighting the water quality assessments generated by states to report on their progress towards meeting requirements of the Clean Water Act[13]. To the average user, however, the IWI appears to offer an overall assessment of the condition of the watershed and its vulnerability to future insult.

The IWI currently provides scores for watershed condition and vulnerability based on an algorithm that combines values from 16 indicators. One set of indicators is used to assess "watershed condition" and another set of indicators is used to assess "watershed vulnerability." Based on these two assessments, watersheds are grouped into categories by condition (i.e., better water quality, water quality with less serious problems, or water quality with more serious problems) and by vulnerability (i.e., high or low). In previous reviews of the IWI, the SAB has recommended enhancements to the suite of indicators included in the Index, and commented on data integration issues associated with the development of the IWI's component indicators and the final watershed scores (EPA Science Advisory Board, 1999; 1997c).

6.4.2 Application of the SAB Framework

Comparison of the IWI indicators to the proposed SAB framework for reporting on ecological condition provides a useful assessment of the coverage provided by the IWI (Table 12). This exercise is particularly appropriate for the IWI, since the website describes itself as a source of information on watershed condition. Of the 16 indicators or composite indicators included in the IWI, only 5 provide direct information on the condition of ecological resources other than chemical and physical characteristics. A sixth indicator, the indicator that reports on the attainment of designated uses, is based in part, in some states, on an assessment of biological community diversity, composition and structure. In the majority of states, however, the determination of designated use attainment is based on physical and chemical water quality parameters.

[13]Section 305(b) of the Clean Water Act (Public Law 92-500) requires states to assess the condition of their surface waters and report their assessments to EPA every two years. The section also requires EPA to summarize the state assessments in a biennial report to the Congress on the quality of the nation's waters.

In short, with the exception of the traditional Agency territory of chemical and physical parameters, the IWI indicators are notably lacking in coverage of the many other important aspects of condition.

Moreover, the IWI includes a preponderance of stressor rather than condition indicators (see Table 12). As discussed in Section 4, information on stressor levels is important for interpreting changes in ecological indicators and for designing and assessing the effectiveness of environmental management approaches. Stressor indicators, however, generally do not provide direct information about the condition or "health" of ecological systems. In the Panel's judgment, therefore, the suite of indicators included in the IWI does not provide a basis for reporting on 'whether rivers, lakes, streams, wetlands, and coastal areas are "well" or "ailing"' (quote excerpted from the description of the IWI at www.epa.gov/iwi).

On the other hand, there is no reason that additional data layers cannot be added. Even if data are not currently available nationwide for particular parameters, highlighting indicators with no data serves two purposes: to educate members of the public regarding the importance of often-overlooked elements of ecological condition (such as hydrology and landscape pattern); and to create public support for the collection of the information. Given the website's popularity and accessibility, and given the fact that it advertises a snapshot of watershed condition, it seems that a more comprehensive list of condition indicators should be used. The EEA checklist could be used to choose these supplemental indicators.

As the IWI indicator and composite indicator list is expanded, it will become increasingly important to have an organizing framework that groups the indicators into understandable categories for presentation. Similarly, it will become increasingly important to have a scientifically and logically justifiable explanation for the composite indicators and maps. The EEA hierarchy can be used for this purpose.

The EEA hierarchy also provides a vehicle for integrating information collected or managed by entities other than EPA. In fact, the current suite of IWI indicators includes a number that are based on data from state programs (e.g., the extent to which waters are meeting designated uses, the existence of fish consumption advisories), other federal agencies (e.g., the estuarine vulnerability data from NOAA, the inventory of dams maintained by the U.S. Army Corps of Engineers), or non-governmental organizations (e.g., data on aquatic species at risk from the Heritage Network). The proposed SAB reporting framework might be used to facilitate and organize a similar integration of information from a variety of data sources to provide an assessment of the condition of ecological systems in watersheds around the country.

Table 12. The IWI Indicators Organized Using the SAB Framework

SAB Reporting Categories and Subcategories			EPA's Index of Watershed Indicators	
			Condition Measures	**Stressor (or Stressor Surrogate) Measures[1]**
Landscape Condition				
	Extent of ecological system/habitat types		% loss of wetlands	
	Landscape Composition			
	Landscape Pattern/Structure			% impervious surface
Biotic Condition				
	Ecosystems and Communities			% of waters that meet designated uses[2]
		Community Extent		
		Community Composition	number of aquatic or wetland-dependent species at risk[3]	
		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	existence of state fish consumption advisories[4]	
Chemical and Physical Characteristics (Water, Air, Soil, Sediment)				
	Nutrient Concentrations			

		Nitrogen		% exceedances of national reference levels for conventional pollutants (ammonia, phosphorus, pH, and dissolved oxygen) in ambient water[6] conventional pollutant loads over permit limits (includes biochemical oxygen demand, total suspended solids, nutrients and others) estuarine pollution susceptiblity index (includes predicted concentrations of N and P)
		Phosphorus		
		Other Nutrients		
	Trace Inorganic and Organic Chemicals			
		Metals	presence of contaminated sediments[5]	presence of contaminated sediments[5] % exceedances of ambient water quality criteria for 4 toxics [Cu, Cr(VI), Ni, Zn][6] toxic loads exceed permit limits (including Cd, Cu, Pb, Hg, and others)
		Other Trace Elements		
		Organic Compounds	presence of contaminated sediments[5]	presence of contaminated sediments[5]
	Other Chemical Parameters			
		pH		% exceedances of national reference levels for conventional pollutants (ammonia, phosphorus, pH, and dissolved oxygen) in ambient water[6] conventional pollutant loads over permit limits (includes biochemical oxygen demand, total suspended solids, nutrients and others)
		Dissolved Oxygen/Redox Potential		
		Salinity		
		Organic Matter		
		Other		
	Physical Parameters			
		sediment		
		water		
Ecological Processes				
	Energy Flow			
		Primary Production		

		Net Ecosystem Production		
		Growth Efficiency		
	Material Flow			
		Organic Carbon Cycling		sediment runoff potential from cropland and pastureland (simulated)–indirect indicator of organic matter flux associated with erosion and sediment transport
		Nitrogen and Phosphorus Cycling	atmospheric deposition of total N (estimated)	potential nitrogen runoff from farm fields; atmospheric deposition of total N (estimated)
		Other Nutrient Cycling		
Hydrology and Geomorphology				
	Surface and Groundwater Flows			% impervious surface
		Pattern of Surface Flows		reservoir impoundment volume (indirect measure of hydrologic modification)
		Hydrodynamics		
		Pattern of Groundwater Flows		
		Salinity Patterns		
		Water Storage	reservoir impoundment volume	
	Dynamic Structural Characteristics			
		Channel/Shoreline Morphology and Complexity		
		Extent and Distribution of Connected Floodplain		
		Aquatic Physical Habitat Complexity		
	Sediment and Material Transport			

		Sediment Supply and Movement		sediment runoff potential from cropland and pastureland (simulated); estuarine pollution susceptibility index (includes particle retention efficiency for estuaries, based on capacity to inflow ratio)
		Particle Size Distribution Patterns		
		Other Material Flux		
Natural Disturbance Regimes				
	Frequency			
	Intensity			
	Extent			
	Duration			

Notes:
1 Human population change, which is included in the IWI, is a driver that affects a number of stressors and indirectly affects a number of condition parameters.
2 Designated uses are established by states in their water quality standards, and may include aquatic life uses.
3 Includes species that are classified by the Heritage Network as critically imperiled, imperiled, or vulnerable, or are listed under ESA as threatened or endangered
4 Fish consumption advisories are developed by states based on a determination of potential risk to humans from consumption of fish or shellfish due to metals, pesticides, PAH, PCBs, dioxins, or other bioaccumulative chemicals.
5 Screening-level assessment based on existing sediment chemistry and biological data compared to various environmental criteria or effects thresholds.
6 Although reporting on % exceedences of various effects-based benchmarks does not provide direct information on environmental condition, the underlying data on ambient concentrations in air, water, sediment, or soil could be reported as condition indicators.

6.5 National Environmental Performance Partnership System (NEPPS)

6.5.1 Background

The National Environmental Performance Partnership System (NEPPS) is a joint state-EPA effort to negotiate environmental priorities and strategies, and to track progress toward environmental protection goals. The goal areas covered in the NEPPS agreements are derived from the Agency's Strategic Plan (EPA, 2000), which in turn closely tracks the Agency's legal mandates. A keystone of NEPPS is reporting on a set of core performance measures, including program "output" measures, "outcome" measures, and "environmental indicators" (loosely correlated with administrative, stressor/exposure, and condition measures, as defined in Figure 1). The 1997 agreement initiating the NEPPS program notes that "EPA and the states will strive to reduce the number of core program output measures in favor of outcome measures and environmental indicators" (EPA, 1997). The agreement goes on to say, "As we gain experience with core performance measures, states and EPA believe that we can reduce our emphasis on traditional output reporting requirements as the primary performance indicator of a state or federal program. We believe that progressive core measures that chart environmental progress and program outcomes will help us reduce our dependence on simply counting the things we do." (EPA, 1997)

The program guidance also notes that the core measures are intended to serve as a minimum set, and in fact the EPA-state agreements negotiated under NEPPS program contain a number of additional reporting measures beyond the required core measures. To date, 35 states have entered into NEPPS agreements with EPA. The initial description of core measures (EPA, 1997) has been updated for many of the EPA goal areas (EPA, 2000).

6.5.2 Application of the SAB Framework

The SAB framework can reasonably be compared to the subset of NEPPS measures that report on goals related to ecological condition (Table 13). For these four goals, only three Core Environmental Measures directly measure ecological condition. Two measures address portions of the SAB's Chemical and Physical Characteristics EEA; many of these chemicals are naturally occurring compounds that may be categorized as condition and/or pollutant (stressor) measures, depending on their concentrations. The remaining measure -- percent of assessed rivers and estuaries with healthy aquatic communities – addresses a subset of the SAB's Biotic Condition EEA. Tables 1 and 4 provide a list of characteristics that should be assessed in order to determine the condition of biological communities, and this checklist could be compared to the measures in individual state NEPPS agreements that will be used to report progress toward the core performance measure.

A more complete view of the NEPPs program emerges when a state agreement is analyzed, because the individual state agreements include many indicators beyond the minimum list required by the Agency. An example of this sort of analysis is presented using the New Jersey NEPPS agreement for FY99-2000 (Appendix D). In the New Jersey example, several additional Essential Ecological Attributes are included, as well as additional categories within the Biotic Condition and Chemical/Physical Characteristics EEAs.

Would the proposed SAB framework enhance the ability of the NEPPS program to communicate with the public, and would the SAB framework be a sensible way to organize the program's indicators? Although there are several ways in which the NEPPS program could profitably use the SAB framework, the Panel concludes that the SAB reporting scheme would be awkward for NEPPS to adopt at the present time. The current reporting categories for NEPPS generally are derived directly from legal mandates, and the NEPPS indicators correlate closely with these mandates. As a result, rearranging the NEPPS indicators into EEA (Table 1) groupings appears strained, particularly for air pollutants. On the other hand, the New Jersey indicators for landscape and biotic condition, hydrology and geomorphology could be grouped effectively into EEAs in order to highlight their ecological significance.

As the NEPPS program evolves towards more measures of environmental quality and fewer measures of administrative effort, the SAB framework can provide greater benefits. If the program moves towards adopting goals such as "maintain healthy watersheds" or "restore natural ecological processes to support native communities," then the SAB framework will provide some direction for the selection of appropriate indicators. At that point, the SAB framework might also provide a useful way to organize the results for reporting.

In the meantime, the SAB framework can provide a useful checklist function for the NEPPS program. For example, with respect to the current indicator that measures the number of estuaries and rivers with healthy aquatic communities, the SAB's Biotic Condition EEA offers a list of important parameters that should be measured. This list may help ensure that metrics are assessed for both biological communities and focal species, and that measures of physical structure are used to determine whether habitat conditions are conducive to sustaining these communities and species. Similarly, the checklist within the Hydrology and Geomorphology EEA relates to processes that maintain the habitats for the aquatic communities in the long term. Reporting on these additional attributes serves an important educational function, in addition to providing a more representative picture of the presence and sustainability of "healthy aquatic communities".

The EEA hierarchy (Table 1) also offers a method to consolidate information from a variety of different programs and/or resource types (i.e., lakes and rivers, forests, rangelands). Using the categories in the Landscape Condition EEA, for example, a state could track the changes in extent and fragmentation of various habitat types, and highlight those habitat types for which information is missing. Moreover, cataloging the NEPPS indicators within the Table 1 categories highlights some areas where the goal-driven indicators are disjointed ecologically (e.g., measures of wetland acreage, without corresponding information on wetland community types; information on benthic communities, without corresponding measures of aquatic physical habitat complexity).

If the states envision the NEPPS reporting program as a planning tool, the SAB framework can be used to highlight useful information that may be missing from current monitoring programs. For example, in a river where aquatic biotic condition is unacceptable, information on water flows and aquatic physical habitat complexity may indicate that changes in these parameters override the improvements expected from decreasing chemical contamination. This information would improve the targeting of environmental protection resources. Similarly, information about the extent and distribution of connected floodplain, coupled with information about the distribution of levees (i.e., channel morphology and complexity) and pattern of surface flows, can help explain and predict flood behavior. This information, in turn, provides insight into the effects of additional development in floodplains and riparian areas.

Table 13. NEPPS Core Environmental Indicators for Environmental Goals Associated with Ecological Resources

Goal/Program Area		Condition Measures	Exposure/Stressor Measures
Clean Air			
	Criteria Air Pollutants1 (ozone, carbon monoxide, particulate matter, lead, nitrogen dioxide, sulfur dioxide)	trends in air quality for each of 6 criteria air pollutants	trends in air quality for each of 6 criteria air pollutants
	Air Toxics		trends in emissions of toxic air pollutants
Clean Waters			
	watershed restoration and protection	% of assessed rivers and estuaries with healthy aquatic communities % change in selected substances found in surface waters	% of assessed waterbodies that support healthy aquatic life use designations (chemical water quality criteria) % change in selected substances found in surface waters
Waste Management and Restoration of Abandoned Waste Sites			
	Store, treat, and dispose of waste in ways that prevent harm to the natural environment.	<u>To Be Developed</u>: indicators of change in the condition of the soil, shallow groundwater, or ecosystems	groundwater releases controlled
Ensure that communities, work places, and ecosystems are safe from pollution.			
	Ground water protection program		Trends in pesticide residues in ground water at several representative locations.
1 National Ambient Air Quality Standards (NAAQS) include Primary Standards to protect public health and Secondary Standards to protect public welfare (e.g., visibility, impacts on agricultural crops, and materials damage). Nonetheless, levels of some criteria air pollutants also have been linked to ecological effects, so changes in ambient levels of these pollutants may effect the condition of ecological resources.			

6.6 Conclusions

a) 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 (Table 1) 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.

b) 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 regrouping characteristics 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.

c) 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" (e.g., 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.

d) 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 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.

e) 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 my 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

Andelman, S.J. and W.F. Fagan. 2000. Umbrellas and flagships: efficient conservation surrogates or expensive mistakes? Proceedings of the National Academy of Sciences of the USA 97:5954-5959.

Anderson, M., P. Bourgeron, M.T. Bryer, R. Crawford, L. Engelking, D. Faber-Langendoen, M. Gallyoun, K. Goodin, D.H. Grossman, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, L. Sneddon, and A.S. Weakley. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume II. The National Vegetation Classification System: list of types. The Nature Conservancy, Arlington, Virginia, USA.

Angermeier, P.L. and J.R. Karr, 1994. Biological integrity versus biological diversity as policy directives: protecting biotic resources. BioScience 44:690-697.

Azam, F., T. Fenchel, J.G. Field, J.S. Gray, L.A. Meyer-Reil and F. Thingstad. 1983. The ecological role of water-column microbes in the sea. Mar. Ecol. Prog. Ser. 10:257-263.

Bailey, R.G. 1995. Descriptions of the ecoregions of the United States. Second Edition. Misc. Publ. 1391. U.S. Department of Agriculture, Washington, DC. 108 pp.

Baker, S. L. and Y. Cai. 1992. The role programs for multiscale analysis of landscape structure using the GRASS geographic information system. Landscape Ecology 7:291-302.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Bessie, W. C., and E. A. Johnson. 1995. The relative importance of fuels and weather on fire behavior in subalpine forests. Ecology 76:747-762.

Bierregaard, R.O., T.E. Lovejoy, V. Kapos, A.A. dos Santos, and R.W. Hutchings. 1992. The biological dynamics of tropical rainforest fragments. BioScience 42 (11):859-866.

Boose, E. R., D. R. Foster, and M. Fluet. 1994. Hurricane impacts to tropical and temperate forest landscapes. Ecological Monographs 64:369-400.

Bormann, F.H. and G.E. Likens. 1979. Pattern and Process in a Forested Ecosystem. Springer-Verlag-New York, Inc. 253 pp.

CALFED Bay-Delta Program. 1999. Ecosystem Restoration Program Plan, Strategic Plan for Ecosystem Restoration. Draft Programmatic EIS/EIR Technical Appendix. June, 1999.

Cairns, J., McCormick, P.V., and Niederlehner, B.R. 1993. A proposed framework for developing indicators of ecosystem health. Hydrobiologia 236:1-44.

Cao, Y., W. P. Williams, and A.. Bark. 1996. Measuring the responses of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic, and diversity indices. Hydrobiologia 341:1-19.

Chesapeake Bay Program. 2001. Chesapeake 2000 and the Bay: Where Are We and Where Are We Going? (November 15, 2001 fact sheet, 4pp.) Available at www.chesapeakebay.net/pubs/Snapc2k.pdf

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. U.S. Department of Interior, Fish and Wildlife Service, Washington, DC.

Cummins, K.W. and M.J. Klug. 1979. Feeding ecology of stream invertebrates. Ann Rev. Ecol. Syst. 10:147-172.

Dale, V.H. and Beyeler, S.C. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.

Dale, V.H., Pearson, S.M., Offerman, H.L., and O'Neill, R.V. 1994. Relating patterns of land-use change to faunal biodiversity in the Central Amazon. Conservation Biology 8: 1027-1036.

Dale, V.H., Lugo, A. MacMahon, J. and Pickett, S. 1998. Ecosystem management in the context of large, infrequent disturbances. Ecosystems 1:546-557.

deCalesta, D.S. 1994. Effects of white-tailed deer on songbirds within managed forests in Pennsylvania. J. Wildl. Manage. 58:711-717.

Engle, V.D., J.K. Summers, G.R. Gaston. 1994. A benthic index of environmental condition of Gulf of Mexico Estuaries. *Estuaries* 17:373-384.

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/

EPA Science Advisory Board. 1994. Evaluation of Draft Technical Guidance for Biological Criteria for Streams and Small Rivers. EPA-SAB-EPEC-94-003.

EPA Science Advisory Board. 1995. SAB Review of Environmental Monitoring and Assessment Program Landscape Component. EPA-SAB-EPEC-LTR-95-002.

EPA Science Advisory Board. 1997a. Review of the Draft Guidance for Lakes and Reservoir Bioassessment and Biocriteria. EPA-SAB-EPEC-LTR-97-007.

EPA Science Advisory Board. 1997b. Science Advisory Board Review of the "Environmental Goals for America: With Milestones for 2005." EPA-SAB-EC-97-007.

EPA Science Advisory Board. 1997c. Development of Phase II of the Index of Watershed Indicators. EPA-SAB-EPEC-ADV-97-003.

EPA Science Advisory Board. 1997d. Problem Formulation Phase of EPA's Watershed Ecological Risk Assessment Case Studies. EPA-SAB-EPEC-ADV-97-001.

EPA Science Advisory Board. 1997e. Evaluation of the Environmental Monitoring and Assessment Program (EMAP) Research Strategy and Research Plan. EPA-SAB-EPEC-97-009.

EPA Science Advisory Board. 1998. Review of EPA's Draft Ecological Research Strategy. EPA-SAB-EPEC-LTR-98-001.

EPA Science Advisory Board. 1999. Review of the Index of Watershed Indicators. EPA-SAB-EPEC-99-014.

EPA Science Advisory Board. 2000. Toward Integrated Environmental Decision-making. EPA-SAB-EC-00-011.

Eyre, F.H. (Ed.). 1980. Forest Cover Types of the United States and Canada. Society of American Foresters, Washington, DC. 148pp.

Fahrig, L., and G. Merriam. 1985. Habitat patch connectivity and population survival. Ecology 66: 1762-1768.

Fleishman, E., D.D. Murphy, P.F. Brussard. 2000. A New Method for Selection of Umbrella Species for Conservation Planning. Ecological Applications 10:569-579.

Forbes, S.A. 1887. The Lake as a Microcosm. Bull. of the Scientific Association (Peoria, IL), 1887: 77-87.

Forman, R.T.T., and M. Godron. 1986. Landscape Ecology. John Wiley & Sons, New York.

Franklin, J.F. 1988. Structural and Temporal Diversity in Temperate Forests. In: Wilson, E.O. (Ed.), Biodiversity. National Academy Press, Washington, DC. Pp 166-175.

Gardner, R.H. and R.V. O'Neill. 1991. Pattern, process and predictability: The use of neutral models for landscape analysis. pp 289-307. In: Turner, M.G. and R.H. Gardner, eds. Quantitative Methods in Landscape Ecology. Springer-Verlag, New York.

Gardner, R.H., A.W. King, and V.H. Dale. 1993. Interactions between forest harvesting, landscape heterogeneity, and species persistence. In: D.C. LeMaster and R.A. Sedjo, eds. Modeling Sustainable Forest Ecosystems, Proceedings of a 1992 workshop in Washington, DC. Published by American Forests, Washington, DC.

Goulder, L.H. and D. Kennedy. 1997. Valuing Ecosystem Services: Philosophical Bases and Empirical Methods. In: Gretchen C. Daily (Ed.). Nature's Services: Societal Dependence on Natural Ecosystems. pp 23-48. Island Press, Washington, DC.

Grime, J. P. 1997. Evidence for the existence of three primary strategies in plants and its relevance to ecology and evolutionary theory. American Naturalist 111: 1169-1194.

Grossman, D.H., D. Faber-Langendoen, A.S. Weakley, M. Anderson, P. Bourgeron, R. Crawford, K. Goodin, S. Landaal, K. Metzler, K.D. Patterson, M. Pyne, M. Reid, and L. Sneddon. 1998. International classification of ecological communities: terrestrial vegetation of the United States. Volume I. The National Vegetation Classification System: development, status, and applications. The Nature Conservancy, Arlington, VA.

Gustafson, E. J. and G. R. Parker. 1992. Relationship between landcover proportion and indices of landscape spatial pattern. Landscape Ecology 7:101-110.

Harper, J. L. 1977. Population in Biology of Plants. New York: Academic Press. 892 pp.

Harris, S. L. 1986. The Other Cascade Volcanoes: Historic Eruptions at Mount St. Helens' Sister Peaks. Pages 20-33 in S. A. C. Keller, editor. Mount St. Helens: Five Years Later. Eastern Washington. University Press, Cheney, Washington.

Harwell, M.A., V. Myers, T. Young, A. Bartuska, N. Gassman, J.H. Gentile, C.C. Harwell, S. Appelbaum, J. Barko, B. Causey, C. Johnson, A. McLean, R. Smola, P. Templet, and S. Tosini. 1999. A Framework for an Ecosystem Integrity Report Card. BioScience 49:543-556.

Hutchinson, G.E. 1967. A Treatise on Limnology, Vol. II: Introduction to Lake Biology and the Limnoplankton. John Wiley. New York, London, Sydney.

Jackson, L.E., J.C. Kurtz, and W.S. Fisher (Ed.s). 2000. Evaluation Guidelines for Ecological Indicators. EPA/620/R-99/005. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC. 107p.

Jones, C. G., J. H. Lawton, and M. Shachak. 1994. Organisms as ecosystem engineers. Oikos 69:373–386.

Jones, K.B., K.H. Riitters, J.D. Wickham, R.D. Tankersley Jr., R.V. O'Neill, D.J. Chaloud, E.R. Smith, and A.C. Neale. 1997. An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas. EPA/600/R-97/130, November 1997. EPA Office of Research and Development, Washington, DC

Karr, J. R. 1991. Biological integrity: a long neglected aspect of water resource management. Ecological applications 1: 66-84.

Karr, J. R. 1993. Defining and assessing ecological integrity: beyond water quality. Environmental Toxicology and Chemistry 12: 1521-1531.

Karr, J. R. and E. W. Chu. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, D.C. 207p.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspective on running water goals. Environmental Management 5: 55-68.

Klein, B.C. 1989. Effects of forest fragmentation on dung and carrion beetle communities in central Amazonia. Ecology 70(6):1715-1725.

Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. 2002. Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance. Environ. Sci. Technol. 36:1202-1211.

Krummel, J. R., R. H. Gardner, G. Sugihara, R. V. O'Neill, and P. R. Coleman. 1987. Landscape patterns in a disturbed environment. Oikos 48:321-324.

Landweber, L.F. and A. P. Dobson (Eds.). 1999. Genetics and the Extinction of Species: DNA and the Conservation of Biodiversity. Princeton University Press. 192 pp.

Levy, K., T.F. Young, and R.M. Fujita. A conceptual framework for choosing indicators of ecological integrity: case study of the San Francisco bay-delta-river system. In: Rappaport, D.J., W.L. Lasley, D.E. Rolston, N.O. Nielson, C.O. Qualset, and A.B. Damania (eds.), Managing for Healthy Ecosystems. CRC/Lewis Press, in press.

Lindemann, R.L. 1942. The trophic-dynamic aspect of ecology. Ecology. 23:399-418.

McDaniels, Timothy L. 2000. Creating and using objectives for ecological risk assessment and management. Environmental Science and Policy 3(6)299-304.

McGarigal, K., and B.J. Marks. 1993. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Unpubl. software, Dept. Forest Science, Oregon State University.

Merritt, R. W. and K. W. Cummins. (Eds.). 1996 (3rd edition). An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co., Dubuque, IA 862p.

Mills, L. S., M. E. Soulé, and D. F. Doak. 1993. The keystone-species concept in ecology and conservation. Bioscience 43:219-224.

Myers V. and C. Sharp. 1997. Inventory of Government Literature on Report Cards. Prepared for the Report Card Working Group of the South Florida Strategic Science Initiative. University of Miami, Center for Marine and Environmental Analyses.

Naiman, R. J. 1988. Animal influences on ecosystem dynamics. Bioscience 38:750-752.

Naiman, R. J., and K. H. Rogers. 1997. Large animals and system-level characteristics in river corridors. BioScience 47:521–529.

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.

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Odum, E. P. 1969. The strategy of ecosystem development. Science 164:262-270.

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

O'Malley, R. Personal Communication: Draft list of indicators being proposed by The Heinz Center for its report, Designing a Report on the State of the Nation's Ecosystems.

O'Neill, R. V., J. R. Krummel, R. H. Gardner, G. Sugihara, B. Jackson, D. L. DeAngelis, B. T. Milne, M. G. Turner, B. Zygmnuht, S. W. Christensen, V. H. Dale, and R. L. Graham. 1988. Indices of landscape pattern. Landscape Ecology 1:153-162.

Paine, R.T. 1974. Intertidal community structure: Experimental studies on the relationship between a dominant competitor and its principal predator. Oecologia 15:93-120.

Plotnick, R.E., R.H. Gardner, R.V. O'Neill. 1993. Lacunarity indices as measures of landscape texture. Landscape Ecology, 8: 201-211.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, J.C., J.C. Stromberg. 1997. The natural flow regime. Bioscience 47(11):769-784.

Power, M. E., D. Tilman, J. A. Estes, B. A. Menge, W. J. Bond, L. S. Mills, G. Daily, J. C. Castilla, J. Lubchenco, and R. T. Paine. 1996. Challenges in the quest for keystones. Bioscience 46:609–620.

Quinn, J.F. and S. Harrison. 1988. Effects of habitat fragmentation and isolation on species richness: evidence from biogeographic patterns. Oecologia 75: 132-140.

Richter, B.D., J.V. Baumgartner, J. Powell, D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4):1163-1174.

Richter, B.D., J.V. Baumgartner, R. Wigington, D.P. Braun. 1997. How much water does a river need? Freshwater Biology 37:231-249.

Romme, W. H., and D. H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. BioScience 32:664J670.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: A review. Conservation Biology 5:18-32.

Senft, R.L., M.B. Coughenour, D.W. Bailey, L.R. Rittenhouse, O.E. Sala, and D.M. Swift. 1987. Large herbivore foraging and ecological hierarchies. BioScience 37:789-799.

Skole, D. and C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: Satellite data from 1978 to 1988. Science 260:1905-1910.

Sparks, R. E. and A. J. Spink. 1998. Preface: disturbance, succession and ecoystem processes in rivers and estuaries – effects of extreme hydrologic events. Regul. Rivers res. Manage. 14: 155-59.

Stoms, D.M. and J.E. Estes. 1993. A remote sensing research agenda for mapping and monitoring biodiversity. International Journal of Remote Sensing 14(10): 1839-1860.

Terborgh, J., J. A. Estes, P. Paquet, K. Ralls, D. Boyd-Heger, B. J. Miller, R. F. Noss. 1999. The role of top carnivores in regulating terrestrial ecosystems. Pp 39-64 In M. E. Soulé and J. Terborgh, eds. Continental conservation: scientific foundations of regional reserve networks. Island Press, Washington, D.C.

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

The Heinz Center. In press. The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. The H. John Heinz III Center for Science, Economics and the Environment. Cambridge University Press, Cambridge, U.K.

Turner, M.G. 1989. Landscape ecology: The effect of pattern on process. Annual Review of Ecology and Systematics, 20:171-197.

Turner, M.G. and Dale, V.H. 1998. What have we learned from large, infrequent disturbances? Ecosystems 1:493-496.

Turner, M. G., and W. H. Romme. 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology 9:59-77.

Turner, M. G., W. L. Baker, C. J. Peterson, and R. K. Peet. 1998. Factors influencing succession: lessons from large, infrequent natrual disturbances. Ecosystems 1:511-523.

U.S. Environmental Protection Agency. 1992. Framework for Ecological Risk Assessment. EPA/630/R-92/001, February 1992. EPA Risk Assessment Forum, Washington, DC.

U.S. Environmental Protection Agency. 1996a. Waquoit Bay Watershed Ecological Risk Assessment : Planning and Problem Formulation. June 13, 1996 draft. EPA Risk Assessment Forum, Washington, DC.

U.S. Environmental Protection Agency. 1996b. Biological Criteria: Technical Guidance for Streams and Small Rivers (Revised Edition). EPA 822-B-96-001. May 1996. Office of Water, Washington, DC.

U.S. Environmental Protection Agency. 1997. EPA Strategic Plan. EPA/190-R-002, September 1997. Office of the Chief Financial Officer, Washington, DC.

U.S. Environmental Protection Agency. 1997. Core Performance Measures for FY1998

U.S. Environmental Protection Agency. 1998a. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002Fa.

U.S. Environmental Protection Agency. 1998b. Lake and Reservoir Bioassessment and Biocriteria: Technical Guidance Document. EPA 841-B-98-007. August 1998. Office of Water, Washington, DC.

U.S. Environmental Protection Agency. 1999. Environmental Outcome-Based Management: Using Environmental Goals and Measures in the Chesapeake Bay Program. EPA 903-R-00-016, CBP/TRS 248/00, July 1999.

U.S. Environmental Protection Agency. 2000. Strategic Plan. EPA 190-R-00-002, September 2000. Office of the Chief Financial Officer, Washington, DC.

U.S. Environmental Protection Agency. 2000. Core Performance Measures for FY2000: Office of Air and Radiation, Office of Water, Office of Solid Waste and Emergency Response, and Office of Enforcement and Compliance Assurance. Available from the Office of Congressional and Intergovernmental Relations, Washington, DC at www.epa.gov/ocir/nepps

U.S. Environmental Protection Agency. 2001. Environmental Monitoring and Assessment Program: West-Research Strategy. February 2001. 37pp. Available at www.epa.gov/emap/wpilot/index.html

U.S. Fish and Wildlife Service. 1981. Standards for the development of habitat suitability index models. Ecological Services manual 103 ESM. Department of the Interior, U.S. Fish and Wildlife Service, Division of Ecological Services, Washington, D.C.

Waters. T. F. 2000. Wildstream: a natural history of the free flowing river. Riparian Press, St. Paul, MN 607p.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20:149-158.

Whitcomb, R. F., C. S. Robbins, J. F. Lynch, B. L Whitcomb, M. K. Klimkiewicz, and D. Bystrak. 1981. Effects of forest fragmentation on the avifauna of the easter decious forest. Pp. 125-205 in R. L. Burgess and D. M. Sharpe, eds. Forest island dynamics in man-dominated landscapes. Springer-Verlag; New York.

White P. S., and S. T. A. Pickett. 1985. Natural disturbance and patch dynamics: An introduction. Pages 3-13 in S. T. A. Pickett and P. W. White, editors. The ecology of natural disturbance and patch dynamics. Academic Press, New York.

Wilson, E.O. (ed.). 1988. Biodiversity. National Academy Press. Washington, D.C.

Wolman, M.G. and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic process. J. Geol. 68:54-74.

APPENDIX A. THE HEINZ CENTER INDICATORS PLACED INTO THE HIERARCHY OF ESSENTIAL ECOLOGICAL INDICATORS

The following table sorts the indicators developed by The Heinz Center (in press) according to the hierarchical list of ecosystem attributes summarized in Table 1. To prepare its overview of the state of the nation's ecosystems, The Heinz Center developed a framework for selecting indicators (summarized in Table 2) with associated decision rules, convened a committee for each of six ecosystem types, requested each committee independently to select indicators according to the framework, and produced a consolidated list of indicators that relate to all ecosystem types. For many of the indicators, data are not yet available.

As the following table shows, the draft set of indicators being recommended by The Heinz Center correspond fairly well with the components of the EEA hierarchy, although all ecosystem types are not represented in all EEAs or categories (e.g., in The Heinz Center report, floods in aquatic systems are not included as disturbances). Thus, use of the EEA hierarchy as a checklist can help to identify potential candidates for future inclusion in The Heinz Center's reports. In addition, the reporting categories embedded in the EEA hierarchy provide a useful structure for grouping The Heinz Center indicators from different ecosystem types, as shown below.

The list of indicators developed by The Heinz Center contains many that would have been considered stressors by some members of the SAB Panel, even though The Heinz Center excluded stressors from consideration. This difference highlights the various schools of thought regarding the definition of stressors versus condition indicators where chemical and physical parameters are concerned.

SAB Reporting Categories and Subcategories	List of Indicators Recommended by The Heinz Center (In press)
Landscape Condition	
Extent of ecological system/habitat types	Area of six ecosystem types and their major subunits Area of more detailed subunits of these ecosystem types (four coastal habitats; six land uses in grasslands; five land uses in farmland ecosystems; size and shape of natural habitat patches in farmlands; acreage of forest cover types; five forest management categories; five shoreline types; total impervious area in urban and suburban regions). Area of ecosystem types or habitats meeting certain quality criteria (altered freshwater ecosystems; vegetated stream bank; percent of all systems that are physically altered or otherwise disturbed)[i]
Landscape Composition	Extent of forest in various patch sizes; area and sizes of patches in grasslands and shrublands; patch sizes of natural areas within urban and suburban regions Presence of particular communities: forest community types with reduced area; % of freshwater plant communities rare or at-risk
Landscape Pattern/Structure	Fragmentation and landscape pattern at the national level; fragmentation of farmlands by development
Biotic Condition	
Ecosystems and Communities	
Community Extent	

		Community Composition	Index of biotic integrity for freshwater animal communities nationwide and for urban streams in particular; benthic index for coastal waters; soil biological condition, as Nematode Maturity Index % non-native cover in non-cropped farmland areas; % non-native cover in forests and grass- and shrublands; % native (or non-native) animal species in freshwater systems; number of non-native species and their ranges in coastal systems; population trends in native and invasive non-native bird species; population trends in selected disruptive species in urban and suburban areas Number of plant and animal species at-risk in forests, freshwater systems, grass- and shrublands, marine waters, and in the nation as a whole; number of "original" species at risk or absent in urban and suburban areas, status of selected wildlife species in farmlands
		Trophic Structure	
		Community Dynamics	
		Physical Structure	
	Species and Populations		
		Population Size	
		Genetic Diversity	
		Population Structure	forest age
		Population Dynamics	
		Habitat Suitability	
	Organism Condition		
		Physiological Status	
		Symptoms of Disease or Trauma	animal deformities and deaths in freshwater systems; marine mortalities
		Signs of Disease	chemicals in fish tissue nationwide
Chemical and Physical Characteristics (Water, Air, Soil, Sediment): SOIL			
	Nutrient Concentrations		
		Nitrogen	nitrate in streams and groundwater in farmlands, forests , grass- and shrublands, urban and suburban areas

		Phosphorus	phosphorous in freshwater systems, and separately in farmland streams, and urban and suburban areas
		Other Nutrients	
		micronutrients	
	Trace Inorganic and Organic Chemicals		
		Metals	Trace chemicals and contaminants in streams, fish tissue, groundwater, and sediments nationwide, and specifically in coastal sediments and urban streams and soils Pesticides in streams and groundwater of farmlands
		Other Trace Elements	
		Organic Compounds	
	Other Chemical Parameters		
		pH	
		Dissolved oxygen/Redox Potential	Dissolved oxygen in coastal waters
		Salinity	Soil salinity in farmlands
		Organic Matter	Soil organic matter in farmlands
		Other	Ozone levels in urban and suburban air
	Physical Parameters		
		soil/sediment	
		water/air	Stream temperature in urban and suburban regions, sea surface temperature Water clarity in freshwater systems
Ecological Processes			
	Energy Flow		
		Primary Production	Plant growth index; production capacity, as chlorophyll concentrations in coastal systems
		Net Ecosystem Production	
		Growth Efficiency	
	Material Flow		
		Organic Carbon Cycling	Carbon storage in forests and grass- and shrublands
		N and P Cycling	nitrogen yields from watersheds and loads from rivers nationwide
		Other Nutrient Cycling	
Hydrology and Geomorphology			

	Surface and Groundwater Flows		
		Pattern of Surface Flows	changes in streamflows nationwide; number and duration of no-flow periods in grass- and shrublands
		Hydrodynamics	
		Pattern of Groundwater Flows	depth to groundwater in grass- and shrublands
		Salinity Patterns	
		Water Storage	groundwater levels nationwide
	Dynamic Structural Characteristics		index of riparian conditions in grass- and shrublands; index of stream habitat quality in freshwater systems generally and specifically in farmlands
		channel/shoreline morphology and complexity	
		extent and distribution of connected floodplain	
		aquatic physical habitat complexity	
	Sediment and Material Transport		
		sediment supply and movement	erosion in coastal systems and farm soils
		particle size distribution patterns	
		other material flux	
Natural Disturbance Regimes			
	Frequency		fire frequency index in forests and grass- and shrublands
	Intensity		
	Extent		areal extent of forest disturbance from several sources
	Duration		

[1]Although each of The Heinz Center's indicators is listed only once, many contain components that inform additional subcategories, as well. These indicators, for example, may contain elements that can be extracted to describe the structural diversity of a particular habitat, which is included as a subcategory within the Biotic Condition EEA.

APPENDIX B. THE SAB REPORTING CATEGORIES ORGANIZED BY LEVEL OF BIOLOGICAL ORGANIZATION AND BY STRUCTURE, COMPOSITION, AND FUNCTION

This figure depicts the EEA categories in which aspects of structure, composition, and function at various hierarchical levels would be reported and assessed in the system proposed in this report. Noss (1990) presented the idea of categorizing biodiversity attributes in a nested hierarchy that included composition, structure, and function at the landscape, community/ecosystem, population/species, and genetic levels of biological organization. More recently, Dale and Beyeler (2001) proposed broadening the scheme to include all attributes related to ecological integrity. The EEA hierarchy presented in this report does not explicitly subdivide ecological integrity attributes according to structure, function, and composition at a variety of scales; it does, however, encompass each of these subdivisions as shown in the figure. The EEAs relating to process span a number of hierarchical scales. Both Landscape Condition and Biotic Condition incorporate structural and functional attributes.

	Structure		Composition	Function		
				Ecological Processes	**Natural Disturbances**	**Hydrology and Geomorphology**
Landscapes	**Landscape Condition** *Landscape Pattern/Structure*		*Extent, Landscape Composition*	*Energy and Material flows*	*Frequency, Intensity, Extent, Duration*	*Surface and Ground Water Flows, Dynamic Structural Characteristics, Sediment and Material Transport*
Ecosystems and Communities	**Chemical and Physical Characteristics** *Nutrients, Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Physical Parameters*	**Biotic Condition** *Physical Structure, Trophic Structure*	*Community Extent, Community Composition*	*Energy and Material flows* *Community Dynamics*	*Frequency, Intensity, Extent, Duration*	*Surface and Ground Water Flows, Dynamic Structural Characteristics, Sediment and Material Transport*
Species and Populations	*Nutrients, Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Physical Parameters*	*Population Structure*	*Population Size*	*Population Dynamics*	*Frequency, Intensity, Extent, Duration*	*Surface and Ground Water Flows, Dynamic Structural Characteristics, Sediment and Material Transport*
Organisms				*Physiological Status, Symptoms of Disease or Impairment, Signs of Disease*	*Frequency, Intensity, Extent, Duration*	*Surface and Ground Water Flows, Dynamic Structural Characteristics, Sediment and Material Transport*
Genes			*Genetic Diversity*		*Frequency, Intensity, Extent, Duration*	*Surface and Ground Water Flows, Dynamic Structural Characteristics, Sediment and Material Transport*

APPENDIX C. BIOTIC CONDITION EEA AND OTHER ESTABLISHED SCHEMES FOR EVALUATING BIOLOGICAL INTEGRITY

Biotic Condition EEA	Index of Biotic Integrity (IBI) Metrics	EPA Streams Biocriteria Guidance[1]	EPA Lakes Biocriteria Guidance: Reservoir Biological Assemblage Index[2]
Ecosystems and Communities			
Community Extent			
Community Composition	total number of species; abundance of certain species; species composition (% of particular species; % tolerant species; number of species in specific categories)	community structure (taxa richness; relative abundance; dominance)	species richness; species abundance
		taxonomic composition (taxa identity; sensitivity; rare/endangered/key taxa)	
Trophic Structure	trophic composition (% omnivores/ insectivores/ top carnivores)		trophic composition
Community Dynamics			
Physical Structure			
Species and Populations			
Population Size			
Genetic Diversity			
Population Structure			
Population Dynamics		predation rate; recruitment rate; trophic dynamics; productivity	reproductive composition
Habitat Suitability (focal species)			
Organism Condition			
Physiological Status		metabolic rates	
Symptoms of Disease or Trauma		disease; anomalies	disease; anomalies
Signs of Disease		contaminant levels	

1From Figure 2-2 (Attributes that should be incorporated into biologial assessment) in EPA, 1996b.
2In addition to biological assessment, the assessment includes information on dissolved oxygen, chlorophyll concentration, and sediment quality. (EPA, 1998b)

APPENDIX D. CONDITION INDICATORS IN THE NEW JERSEY NEPPS AGREEMENT (FY99-2000)[1]

SAB Reporting Categories and Subcategories			**Environmental Condition Indicators in the New Jersey NEPPS Agreement for FY99/2000**
Landscape Condition			
	Extent of ecological system/habitat types		wetlands acreage (freshwater and coastal); statewide forest acreage
	Landscape Composition		% tree cover (canopy) in urban/suburban areas; types of land cover
	Landscape Pattern/Structure		land cover change; acreage of fragmented forest
Biotic Condition			
	Ecosystems and Communities		
		Community Extent	
		Community Composition	benthic macroinvertebrate communities (non-tidal waters); tree species composition and species diversity (forest, including urban forest); number, type, and extent of noxious invasive exotic plant species statewide
		Trophic Structure	
		Community Dynamics	
		Physical Structure	
	Species and Populations		
		Genetic Diversity	
		Population Size	fish and shellfish population measures; tree species population and distribution; endangered species populations statewide; priority landscape species; horseshoe crab egg density and migratory bird populations; beach nesting bird populations
		Population Structure	
		Population Dynamics	tree species growth rate and mortality; adverse reproductive outcomes in raptors and selected waterbirds
		Habitat Suitability	
	Organism Condition		
		Physiological Status	
		Symptoms of Disease or Impairment	

		Signs of Disease	fish tissue concentrations of bioaccumulative chemicals that are toxic to humans (e.g., mercury, PCBs, dioxin and certain pesticides)
Chemical and Physical Characteristics: AIR			
	Nutrient Concentrations		
		Nitrogen	NO2 levels in ambient air
		Phosphorus	
		Other Nutrients	
	Trace Inorganic and Organic Chemicals		
		Metals	concentrations of air toxics (metals associated with suspended particulate matter)
		Other Trace Elements	
		Organic Compounds	VOC levels in ambient air
	Other Chemical Parameters		
		pH	
		Dissolved Oxygen/Redox Potential	
		Salinity	
		Organic Matter	
		Other	ozone levels in ambient air
	Physical Parameters		particulate matter in ambient air
Chemical and Physical Characteristics: WATER (Surface and Ground Water)			
	Nutrient Concentrations		
		Nitrogen	nitrate levels in ground water; total N, ammonia, and nitrate in streams
		Phosphorus	total P in streams
		Other Nutrients	
	Trace Inorganic and Organic Chemicals		
		Metals	metal levels in ground water
		Other Trace Elements	
		Organic Compounds	VOC levels in ground water; pesticides concentrations in ground water; detectable pesticide residues in ground and surface waters (monitored)[1]
	Other Chemical Parameters		
		pH	

		Dissolved Oxygen/Redox Potential	in-stream dissolved oxygen
		Salinity	chloride in ground water
		Organic Matter	
		Other	radioactivity in ground water, and in surface water discharge at nuclear power plants
	Physical Parameters		
Chemical and Physical Characteristics: SEDIMENT			
	Nutrient Concentrations		
		Nitrogen	
		Phosphorus	
		Other Nutrients	
	Trace Inorganic and Organic Chemicals		sediment contaminants
		Metals	
		Other Trace Elements	
		Organic Compounds	
	Other Chemical Parameters		
		pH	
		Dissolved Oxygen/Redox Potential	
		Salinity	
		Organic Matter	
		Other	radioactivity in tidal sediments
	Physical Parameters		
Chemical and Physical Characteristics: SOIL			
	Nutrient Concentrations		
		Nitrogen	
		Phosphorus	
		Other Nutrients	
	Trace Inorganic and Organic Chemicals		
		Metals	
		Other Trace Elements	
		Organic Compounds	
	Other Chemical Parameters		
		pH	

		Dissolved Oxygen/Redox Potential	
		Salinity	
		Organic matter	
		Other	
	Physical Parameters		
Ecological Processes			
	Energy Flow		
		Primary Production	trophic status of public lakes
		Net Ecosystem Production	
		Growth Efficiency	
	Material Flow		
		Organic Carbon Cycling	
		N and P Cycling	
		Other Nutrient Cycling	
Hydrology and Geomorphology			
	Surface and Groundwater Flows		
		Pattern of Surface Flows	stream flows, including base flow levels and flood flows
		Hydrodynamics	
		Pattern of Groundwater Flows	
		Salinity Patterns	
		Water Storage	water levels in reservoirs; ground water supplies
	Dynamic Structural Characteristics		
		Channel/Shoreline Morphology and Complexity	shoreline changes
		Extent and Distribution of Connected Floodplain	
		Aquatic Physical Habitat Complexity	
	Sediment and Material Transport		
		Sediment Supply and Movement	
		Particle Size Distribution Patterns	
		Other Material Flux	
Natural Disturbance Regimes			
	Frequency		

	Intensity	
	Extent	
	Duration	

[1]Some of the indicators included in the NJ NEPPS set of condition indicators--e.g., those relating to xenobiotic chemicals-- are classified as stressor indicators under the SAB framework but are included as condition indicators by The Heinz Center.

Sources: NJ DEP. 1998. Environmental Indicators Technical Report: National Environmental Performance Partnership System (NEPPS). June 1998.

Environmental Indicators in the FY99-2000 New Jersey NEPPS Performance Partnership Agreement. (At www.state.nj.us/dep/dsr/nepps.htm).