Chapter 6

Ecological Condition

Contents

6.1 Introduction

The term "ecological condition" refers to the state of the physical, chemical, and biological characteristics of the environment, and the processes and interactions that connect them. Understanding ecological condition is crucial, because humans depend on healthy ecological systems for food, fiber, flood control, and other benefits,[1] and many Americans attribute deep significance and important intangible benefits to ecological systems and their diverse flora and fauna.[2] As noted in the introduction to this report, this chapter focuses on critical ecosystem characteristics that are affected simultaneously by stressors in multiple media, rather than those whose trends can be definitively shown to be the results of trends in particular air, water, or land stressors. The ability to report on ecological condition remains significantly limited by the lack of indicators, but this chapter at least provides a framework for examining ecological condition.

EPA's mission, broadly stated, is "to protect human health and to safeguard the natural environment—air, water, and land—upon which life depends."[3] The translation of the mission into programs, initiatives, and research efforts continues to evolve within the Agency and is reflected in program goals, regulatory programs, and collaborative and educational efforts. EPA, other federal agencies, and state agencies collectively bear responsibility for ensuring the protection of ecological systems, including forests, public lands, oceans and estuaries, and particular species or groups of species. Trends in ecological condition provide insight into the degree to which the natural environment is being protected.

In this chapter, EPA seeks to assess trends in critical attributes of ecological condition on a national scale, using indicators to address five fundamental questions:

- **What are the trends in the extent and distribution of the nation's ecological systems?** This question examines trends in the overall extent (e.g., area and location) of different kinds of ecological systems (e.g. forests, undeveloped lands, and watersheds) and of spatial patterns in the distribution of ecological systems that affect interactions of nutrients, energy, and organisms.
- **What are the trends in the diversity and biological balance of the nation's ecological systems?** This question explores trends in the types and numbers of species that live within ecological systems. The question also examines biological balance in terms of the proportional distributions of species and the influence of interactions among native and invasive species on the stability of ecological systems.
- **What are the trends in the ecological processes that sustain the nation's ecological systems?** This question

EPA's 2008 Report on the Environment (ROE): Essentials

ROE Approach

This 2008 Report on the Environment:

- Asks questions that EPA considers important to its mission to protect human health and the environment.
- Answers these questions, to the extent possible, with available indicators.
- Discusses critical indicator gaps, limitations, and challenges that prevent the questions from being fully answered.

ROE Questions

The air, water, and land chapters (Chapters 2, 3, and 4) ask questions about trends in the condition and/or extent of the environmental medium; trends in stressors to the medium; and resulting trends in the effects of the contaminants in that medium on human exposure, human health, and the condition of ecological systems.

The human exposure and health and ecological condition chapters (Chapters 5 and 6) ask questions about trends in aspects of health and the environment that are influenced by many stressors acting through multiple media and by factors outside EPA's mission.

ROE Indicators

An indicator is derived from actual measurements of a pressure, state or ambient condition, exposure, or human health or ecological condition over a specified geographic domain. This excludes indicators such as administrative, socioeconomic, and efficiency indicators.

Indicators based on one-time studies are included only if they were designed to serve as baselines for future trend monitoring.

All ROE indicators passed an independent peer review against six criteria to ensure that they are useful; objective; transparent; and based on data that are high-quality, comparable, and representative across space and time.

Most ROE indicators are reported at the national level. Some national indicators also report trends by region. EPA Regions were used, where possible, for consistency and because they play an important role in how EPA implements its environmental protection efforts.

Several other ROE indicators describe trends in particular regions as examples of how regional indicators might be included in future versions of the ROE. They are not intended to be representative of trends in other regions or the entire nation.

EPA will periodically update and revise the ROE indicators and add new indicators as supporting data become available. In the future, indicators will include information about the statistical confidence of status and trends. Updates will be posted electronically at http://www.epa.gov/roe.

Additional Information

You can find additional information about the indicators, including the underlying data, metadata, references, and peer review at http://www.epa.gov/roe.

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1 Daily, G.C., ed. 1997. Nature's services: Societal dependence on natural ecosystems. Washington, DC: Island Press.

2 Norton, B. 1988. Commodity, amenity, and morality: The limits of quantification in valuing biodiversity. In: Wilson, E.O., ed. Biodiversity. Washington, DC: National Academies Press. p. 521.

3 U.S. EPA. 2007. About EPA. <http://www.epa.gov/epahome/aboutepa.htm#mission>

focuses on trends in the critical processes that sustain ecological systems, such as primary and secondary productivity, nutrient cycling, decomposition, and reproduction.

- **What are the trends in the critical physical and chemical attributes of the nation's ecological systems?** This question addresses trends in the physical and chemical attributes of ecological systems. Physical attributes can include climatological patterns, hydrology, and electromagnetic radiation, as well as major physical events that reshape ecological systems, such as fires, floods, and windstorms. This question also examines chemical attributes such as pH, oxidation-reduction potential, and nutrient levels.
- **What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?** This question examines trends in biomarkers of exposure to contaminants that are particularly important to the health of plants and animals as well as to humans who consume such organisms.

These ROE questions are posed without regard to whether indicators are available to answer them. This chapter presents the indicators available to answer these questions, and also points out important gaps where nationally representative data are lacking.

While the indicators of ecological condition (and those in the previous chapter, "Human Exposure and Health") may be directly influenced by pollutants, other environmental stressors, and complex interactions among these factors, the indicators are not intended to confirm direct causal relationships.

6.1.1 The Ecological Condition Paradigm

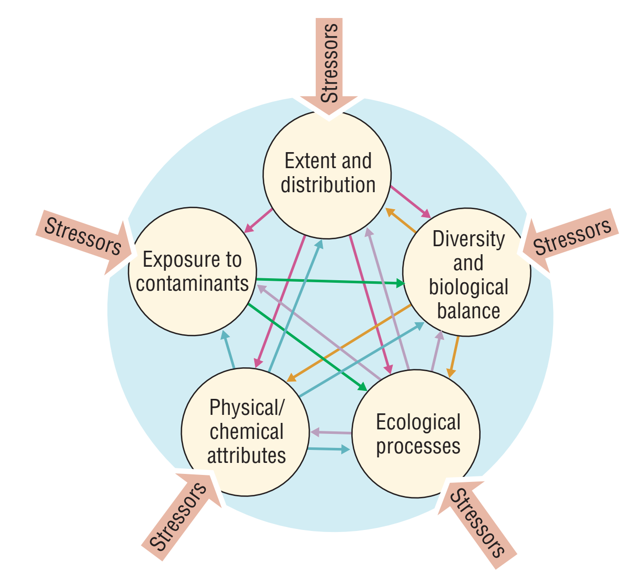
Because ecological systems are dynamic assemblages of organisms that have more or less continuously adapted to a variety of natural stressors over shorter (e.g., fire, windstorms) and longer (e.g., climate variations) periods of time, measuring ecological condition is a complicated endeavor. It is not as straightforward as monitoring water or air for temperature or concentrations of pollutants. The complexity of interactions within ecological systems makes determination of the condition of a natural system difficult.[4] In addition, people have altered natural ecological systems to increase the productivity of food, timber, fish, and game and to provide the infrastructure needed to support a modern society. How should the ecological condition of these altered ecological systems be measured and against what reference points?

Ecological systems are not necessarily naturally occurring entities with well-defined, mutually exclusive boundaries; rather, they are constructs with boundaries determined for human scientific or management purposes. Consequently there are many ways to define ecological systems, including by the predominant biota, spatial scales, and physical characteristics. These factors further complicate the definition and measurement of ecological condition. Several recent reports by experts in the field have provided guidance for current and future efforts, however.

The National Research Council (NRC) report *Ecological Indicators for the Nation*[5] provides an introduction to recent national efforts to measure ecological condition and a thoughtful discussion of the rationale for choosing indicators. EPA's Science Advisory Board (SAB) also proposed a *Framework for Assessing and Reporting on Ecological Condition.*[6] The framework identified six essential attributes of ecological systems: landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology and geomorphology, and natural disturbance regimes. The SAB report is organized around questions about trends in each of these attributes, consolidating the last three into a single attribute. Neither report identifies specific methodologies, network designs, or actual datasets. The SAB and NRC documents provide the foundation for the questions that are addressed within this chapter.

Exhibit 6-1 is a conceptual depiction of the events that link environmental changes and ecological outcomes in this paradigm. "Stressors," indicated by thick arrows, represent factors such as insect outbreaks or contaminants affecting the system. These stressors act directly on one or more of the "essential ecological attributes" shown in the circles in the center of the diagram. Most of these attributes can, in turn, act on and be acted on by others. The web of arrows among the indicators

Exhibit 6-1. Ecological condition paradigm



Stressors (shown as ⇦) affect ecological attributes directly and also indirectly through feedback (interaction) among the attributes (e.g., ↑).

[4] Ehrenfeld, D.H. 1992. Ecosystem health and ecological theories. In: Costanza, R., B.G. Norton, and B.D. Haskell, eds. Ecosystem health: New goals for environmental management. Washington, DC: Island Press. pp. 135-143.

[5] National Research Council. 2000. Ecological indicators for the nation. Washington, DC: National Academies Press. <http://www.nap.edu/openbook.php?isbn=0309068452>

[6] U.S. Environmental Protection Agency. 2002. A framework for assessing and reporting on ecological condition: An SAB report. EPA/SAB/EPEC-02/009. <http://www.epa.gov/sab/pdf/epec02009a.pdf>

illustrates some of the possible interactions. Effects on ecological attributes can be direct or indirect. The diagram illustrates the fact that changes in ecological structure and processes provide important feedback on the chemical and physical structure of the environment in which these changes occur. The overall changes in the attributes result in altered structure and function of ecological systems, which in turn lead to outcomes (positive or negative) about which society is concerned.

There have been other notable efforts conducted by EPA and other federal agencies and institutions to describe the ecological condition of the nation, either in total or by type of ecological systems. These efforts include both indicator-based and integrative approaches. The indicator-based approaches, such as this report, use indicators to assess ecological condition. The integrated assessments do not rely on indicators; rather, they comprehensively assess a wide range of data in order to arrive at an overall picture of the status and trends in ecological systems. Indicator approaches offer the advantage of drawing attention to important trends and do not require an extensive background in ecology, but are not able to capture the complex interactions that characterize ecological systems.

6.1.2 Overview of the Data

This chapter, like the others in this report, is not intended to be an exhaustive treatment of the condition of all ecological systems in the nation. Rather, it provides a snapshot of status or trends using the few ecological condition indicators that are available at the national level and that meet the ROE indicator criteria. Because ecological condition depends critically on the physical and chemical characteristics of land, air, and water, this chapter draws on indicators from Chapters 2 through 4 of this report. Those chapters should be consulted for the data sources of those indicators. Many of the indicators continue to be drawn from The H. John Heinz III Center for Science, Economics, and the Environment report *The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States.*

Most of the data relied upon come from surveillance and monitoring surveys. The key data sources for this chapter reflect the fact that monitoring ecological condition is a multi-organizational task. Organizations in addition to EPA that are responsible for collecting the data to support indicators in this chapter include the U.S. Department of Commerce (National Oceanic and Atmospheric Administration), National Aeronautics and Space Administration, U.S. Department of Agriculture (Forest Service, Agricultural Research Service, National Agricultural Statistics Service, and Natural Resource Conservation Service), U.S. Department of Interior (U.S. Geological Survey and U.S. Fish and Wildlife Service), and NatureServe (a private research organization).

Programs such as the U.S. Department of Agriculture Forest Inventory and Analysis program and the Natural Resources Inventory have a long history because they measure aspects of the environment that are critical to multi-billion-dollar industries (e.g., timber, crops). Programs with a strictly "ecological" focus (e.g., the U.S. Geological Survey's National Water Quality Assessment Program [NAWQA], the multi-agency Multi-Resolution Land Characteristics [MRLC] Consortium, and EPA's Environmental Monitoring and Assessment Program [EMAP]) are more recent, but equally informative.

The major challenges involve adequate coverage of the diverse aspects of ecological condition. For example, there are numerous groups of animals and plants, but there are ROE indicators for only some of these. Major groups known to be undergoing changes, such as amphibians, are not captured by the ROE indicators. These challenges and limitations are described in each of the subsections.

This chapter presents only data that meet the ROE indicator definition and criteria (see Box 1-1, p. 1-3). Note that non-scientific indicators, such as administrative and economic indicators, are not included in this definition. Thorough documentation of the indicator data sources and metadata can be found online at http://www.epa.gov/roe. All indicators were peer-reviewed during an independent peer review process (again, see http://www.epa.gov/roe for more information). Readers should not infer that the indicators included reflect the complete state of knowledge on current indicators of U.S. ecological condition. Many other data sources, publications, and site-specific research projects have contributed to the current understanding of status and trends in indicators of U.S. ecological condition, but are not used in this report because they do not meet some aspect of the ROE indicator criteria.

6.1.3 Organization of This Chapter

The remainder of this chapter is organized into five sections, corresponding to the five questions EPA is seeking to answer regarding trends in ecological condition. Each section introduces the question and its importance, presents the National Indicators selected to help answer the question, and discusses what the indicators, taken together, say about the question. Some of the National Indicators presented are broken down by EPA Regions or other appropriate regions. In addition, several Regional Indicators are presented that capture regional trends of particular interest to EPA Regions. These Regional Indicators serve as models that could potentially be expanded to other EPA Regions in the future. A map showing the EPA Regions (and states within each Region) is provided in Chapter 1 (Exhibit 1-1). Each section concludes by highlighting the major challenges to answering the question and identifying important information gaps.

Table 6-1 lists the indicators used to answer the five questions in this chapter and shows the locations where the indicators are presented.

Table 6-1. Ecological Condition—ROE Questions and Indicators

Question	Indicator Name	Section	Page
What are the trends in the extent and distribution of the nation's ecological systems?	Land Cover (N/R)	4.2.2	4-7
	Forest Extent and Type (N/R)	6.2.2	6-8
	Forest Fragmentation (N/R)	6.2.2	6-11
	Wetland Extent, Change, and Sources of Change (N)	3.4.2	3-32
	Land Use (N)	4.3.2	4-14
	Urbanization and Population Change (N)	4.3.2	4-19
	Land Cover in the Puget Sound/Georgia Basin (R)	4.2.2	4-10
	Ecological Connectivity in EPA Region 4 (R)	6.2.2	6-13
	Relative Ecological Condition of Undeveloped Land in EPA Region 5 (R)	6.2.2	6-14
What are the trends in the diversity and biological balance of the nation's ecological systems?	Coastal Benthic Communities (N/R)	3.5.2	3-44
	Benthic Macroinvertebrates in Wadeable Streams (N)	3.2.2	3-21
	Bird Populations (N)	6.3.2	6-20
	Fish Faunal Intactness (N)	6.3.2	6-21
	Submerged Aquatic Vegetation in the Chesapeake Bay (R)	3.5.2	3-46
	Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest (R)	6.3.2	6-23
What are the trends in the ecological processes that sustain the nation's ecological systems?	Carbon Storage in Forests (N)	6.4.2	6-28
What are the trends in the critical physical and chemical attributes of the nation's ecological systems?	U.S. and Global Mean Temperature and Precipitation (N)	6.5.2	6-32
	Sea Surface Temperature (N)	6.5.2	6-37
	Streambed Stability in Wadeable Streams (N)	3.2.2	3-11
	High and Low Stream Flows (N)	3.2.2	3-8
	Sea Level (N)	6.5.2	6-39
	Nitrogen and Phosphorus Loads in Large Rivers (N)	3.2.2	3-17
	Nitrogen and Phosphorus in Wadeable Streams (N)	3.2.2	3-13
	Nitrogen and Phosphorus in Streams in Agricultural Watersheds (N)	3.2.2	3-15
	Lake and Stream Acidity (N)	2.2.2	2-42
	Hypoxia in the Gulf of Mexico and Long Island Sound (R)	3.5.2	3-48
What are the trends in biomarkers of exposure to common environmental contaminants in plants and animals?	Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
	Contaminants in Lake Fish Tissue (N)	3.8.2	3-63
	Ozone Injury to Forest Plants (N)	2.2.2	2-24

N = National Indicator

R = Regional Indicator

N/R = National Indicator displayed at EPA Regional scale

6.2 What Are the Trends in the Extent and Distribution of the Nation's Ecological Systems?

6.2.1 Introduction

Ecological systems,[7] ranging from forests and watersheds to wetlands and coral reefs, are the foundation of the environment. An ecological system can be defined as a spatially explicit unit of the Earth that includes all of the organisms, along with all components of the abiotic environment, within its boundaries. Ecological systems are not isolated but blend into and interact with other systems. The spatial coverage and arrangement of ecological systems influence the types of animals and plants that are present; the physical, chemical, and biological processes in the system; and the resiliency of the systems to perturbations.[8] Ecological systems influence water and nutrient cycles, the building of soils, the production of oxygen, sequestration of carbon, and many other functions important for the health of the planet and people who depend on them.

This section examines trends in the extent and distribution of ecological systems. *Extent* refers to the physical coverage of an ecological system; it can be reflected as area or percent compared to a baseline or total area. *Distribution* includes the pattern or arrangement of the components of an ecological system and is dependent on the scale of analysis. For example, the national distribution of forests can be estimated by a percent coverage, but within a stand of trees the distribution may involve patterns of gaps, species, and edge/interior ratios. As noted in Section 6.1.1, ecological systems can be defined by predominant biota, spatial scales, and physical characteristics. Extent indicators typically are based on physical and biological characteristics that are observable by remote sensing, with indistinct boundaries operationally defined according to some scientific or resource management construct.[9]

As noted in Chapter 1, safeguarding the natural environment is an integral part of EPA's mission. EPA traditionally has been most concerned with maintaining the quality of air, water, and land necessary to support balanced biological communities and the processes that support them; however, the success of these efforts requires that ecological systems not be altogether lost or fragmented. The potential influences of pollutants on the extent and distribution of ecological systems are a prime concern, and, in turn, the extent and distribution of ecological systems have far-reaching influences on air and water quality.

Apparent trends in extent and distribution of ecological systems depend on the temporal and spatial scale of assessment. For this reason, both National and Regional Indicators are particularly valuable. *Temporal* changes occur naturally over long time scales, such as those associated with geological and climatological forces (e.g., glaciation). Change can also occur more quickly as a result of direct shifts in land use (e.g., forest to development and historical filling of wetlands), alterations of nutrient and hydrological cycles (e.g., dam removal), introduction of invasive species (e.g., Asian carp), pollutant exposure (e.g., acid rain), or extreme weather events, which all act over comparatively short time periods. Thus, trends can be the result of natural forces or may be accelerated by human activity.

The *spatial* scale of alterations also represents a significant factor in tracking ecological condition. Alterations that are short in duration and local in nature (e.g., seasonal droughts or a windfall in a closed forest canopy) may not have large-scale or lasting effects on ecological systems. Alterations that are chronic in nature and occur over large areas may affect entire ecosystems over long periods of time, especially if they affect soil formation, microclimate, refugia for recolonizing species, etc. Particularly relevant discussions of the importance of scale in ecological processes, monitoring, and management can be found in a number of relatively recent publications.[10,11,12]

Different regions and different ecological systems respond to stressors in different ways, resulting in unique regional distributions of species and habitats. The result is that across any slice of landscape the extent and distribution of ecological systems may shift.[13] In the case of habitat loss, large impacts may occur and the extent of coverage may be reduced or eliminated altogether. More subtle changes in ecological systems can occur that are not captured in simple metrics of extent and distribution. These changes are discussed in later sections of this chapter.

Fragmentation, the division of previously uninterrupted habitat, can have either negative or positive impacts on communities.[14] Examples of fragmentation include building highways through a forest, damming a river in a manner that limits migration of fish, or developing waterfronts in a manner that splits apart bordering marshlands. Fragmentation and the increasing area of edge habitat may force migrating species to find new transport corridors, may allow new species (e.g., competitors, pathogens, weeds) to enter areas previously

[7] Likens, G. 1992. An ecosystem approach: Its use and abuse. Excellence in ecology, book 3. Oldendorf/Luhe, Germany: Ecology Institute.

[8] Wilson, E.O. 1992. The diversity of life. Cambridge, MA: Belknap Press.

[9] The H. John Heinz III Center for Science, Economics, and the Environment. 2005. The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States. New York, NY: Cambridge University Press. Web update 2005. <http://www.heinzctr.org/ecosystems/forest/frgmnt.shtml>

[10] Peterson, D.L., and V.T. Parker. 1998. Ecological scale: Theory and applications. New York: Columbia University Press.

[11] Niemi, G., and M. McDonald. 2004. Application of ecological indicators. Annu. Rev. Ecol. Evol. Syst. 35:89-111.

[12] Findlay, C.S., and L. Zheng. 1997. Determining characteristic stressor scales for ecosystem monitoring and assessment. J. Environ. Manage. 50(3):265-281.

[13] The H. John Heinz III Center for Science, Economics, and the Environment. 2005. Forest pattern and fragmentation. In: The state of the nation's ecosystems: Measuring the lands, waters, and living resources of the United States. New York, NY: Cambridge University Press. Web update 2005. <http://www.heinzctr.org/ecosystems/forest/frgmnt.shtml>

[14] Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. J. Wildl. Manage. 61(3):603-610.

blocked from immigration, and in some cases may actually increase biodiversity.[15] Regardless of the impact, fragmentation likely will result in shifting distributions of species.

Trends in ecological system extent and distribution are highly dependent on the evaluation scale. At one scale, coastal wetlands may appear to be uninterrupted and uniform. However, at a more refined scale, edges, patches, corridors associated with tidal creeks, and discontinuous distributions of species become evident. Defining systems in terms of local organization or predominant species facilitates discussion and analysis, but may also obscure the important linkages among systems across landscapes. Therefore, while it is helpful to discuss trends in the extent and distribution of systems such as wetlands or forests, each system is tied into global water, nutrient, carbon, and energy cycles.

The indicators discussed in this section fall into three broad categories: indicators of the extent and distribution of forests, indicators of the extent and distribution of wetlands, and indicators of land use.

6.2.2 ROE Indicators

In this question, trends in the extent and distribution of ecological systems are evaluated for a subset of systems including forests, wetlands, undeveloped lands, and developed lands.

To answer the question on extent and distribution of ecological systems, this report relies primarily on six National Indicators and three Regional Indicators (Table 6-2). Data on trends in extent and distribution of ecological systems come from a variety of sources, including satellite remote sensing, geographic information systems, and independent field studies. Information for the indicators discussed in this section is drawn from several national assessments including the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis program, the U.S. Fish and Wildlife Service's Wetlands Status and Trends Survey, the National Land Cover Dataset/Database (NLCD) for 1992 and 2001, and the USDA National Resources Inventory.

Table 6-2. ROE Indicators of Trends in Extent and Distribution of the Nation's Ecological Systems

National Indicators	Section	Page
Land Cover (N/R)	4.2.2	4-7
Forest Extent and Type (N/R)	6.2.2	6-8
Forest Fragmentation (N/R)	6.2.2	6-11
Wetland Extent, Change, and Sources of Change	3.4.2	3-32
Land Use	4.3.2	4-14
Urbanization and Population Change	4.3.2	4-19
Regional Indicators	**Section**	**Page**
Land Cover in the Puget Sound/Georgia Basin	4.2.2	4-10
Ecological Connectivity in EPA Region 4	6.2.2	6-13
Relative Ecological Condition of Undeveloped Land in EPA Region 5	6.2.2	6-14

N/R = National Indicator displayed at EPA Regional scale

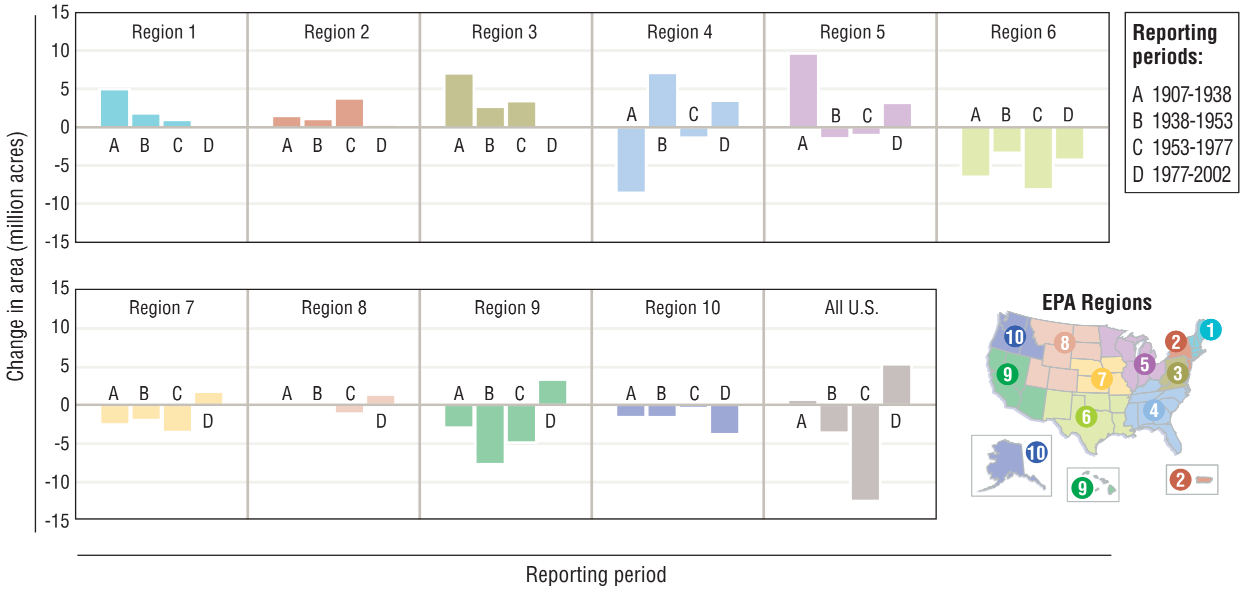
INDICATOR | Forest Extent and Type

The forests of the U.S. cover extensive lands in both the eastern and western thirds of the country. While the amount of forest land has remained nearly unchanged since the beginning of the 20th century, regional changes both in amount and types of forest cover have occurred as a result of changing patterns of agriculture and development. The distribution of various forest cover types is a critical determinant of the condition of forest ecosystems.

This indicator is based on data from the U.S. Department of Agriculture (USDA) Forest Service Forest Inventory and Analysis (FIA) program. The FIA program, using a statistical survey design and comparable methods across the U.S., collects various data that help assess the extent, type, age, and health of the nation's forest land. Because the surveys are repeated over time, the FIA data provide an indication of trends in both the extent and composition

[15] Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annu. Rev. Ecol. Syst. 34:487-515.

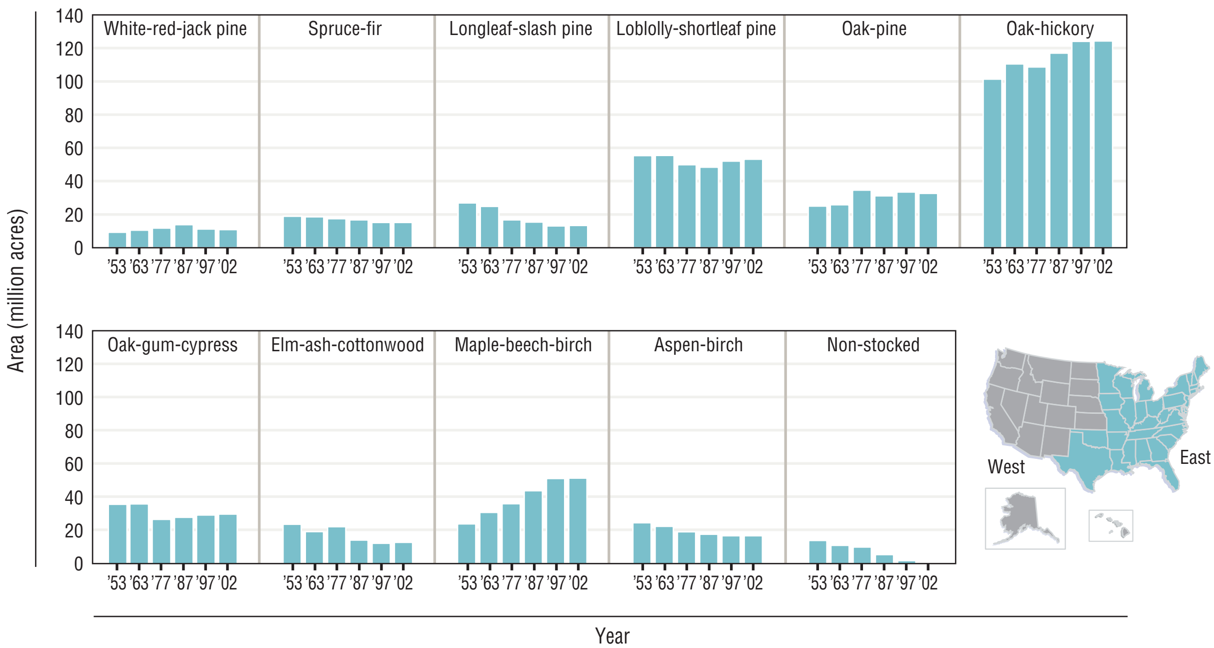
Exhibit 6-2. Changes in the extent of forest land in the U.S. by EPA Region, 1907-2002[a]



[a]**Coverage:** All 50 states.

Data source: *Smith et al., 2001, 2004*

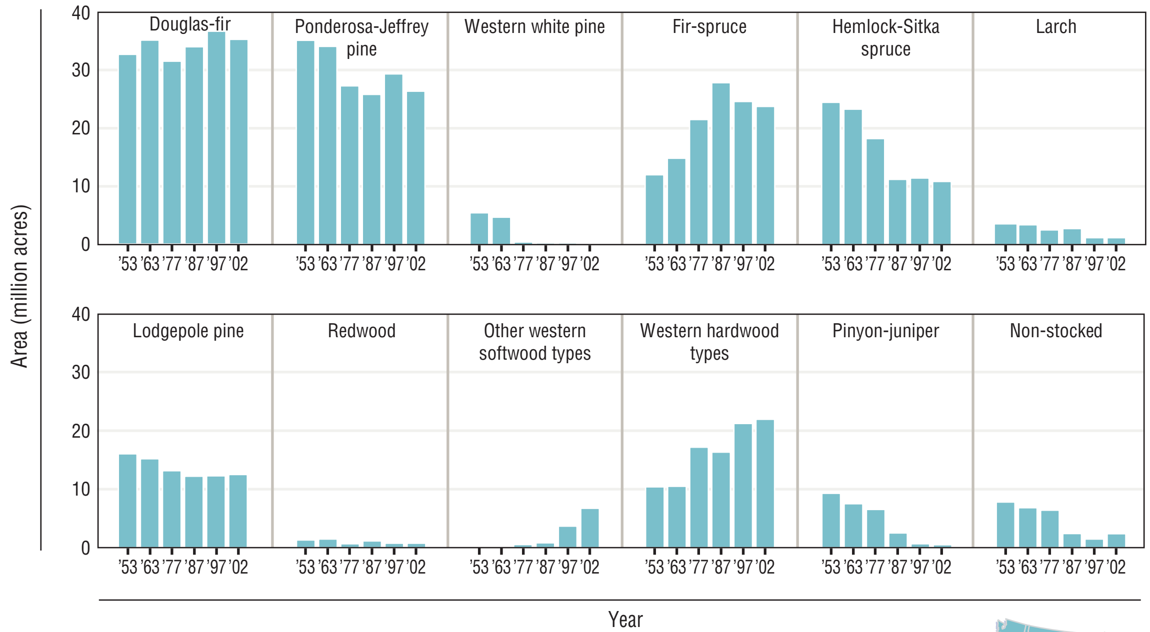
Exhibit 6-3. Timberland area in the eastern U.S. by forest type, 1953-2002[a]

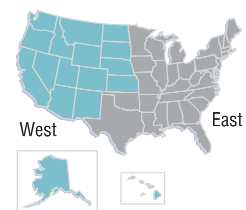


[a]**Coverage:** States in the eastern U.S., based on USDA Forest Service reporting regions (see map at right). These data cover timberland, as defined by the Forest Service's Forest Inventory and Analysis (FIA) Program. Approximately 94% of the forest land in the eastern states is timberland.

Data source: *Smith et al., 2001, 2004*

Exhibit 6-4. Timberland area in the western U.S. by forest type, 1953-2002[a]





[a]**Coverage:** States in the western U.S. (including Alaska and Hawaii), based on USDA Forest Service reporting regions (see map at right). These data cover timberland, as defined by the Forest Service's Forest Inventory and Analysis (FIA) Program. Approximately 39% of the forest land in the western states is timberland.

Data source: *Smith et al., 2001, 2004*

of forest land. The extent data are collected for all forest lands across the nation, but species composition data over time are only available for *timberland* as defined by FIA data collection procedures (that is, forests capable of producing at least 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or regulation). Timberland makes up 94 percent of the forest land area in the eastern U.S. and 39 percent of forest land in the western U.S. as of 2002 (Smith et al., 2004). Extent data are collected for individual states, but have been summarized by EPA Region for this indicator.

What the Data Show

After a slight increase in forest land nationwide between 1907 and 1938, forest acreage decreased by more than 16 million acres between 1938 and 1977, before increasing by 5.3 million acres over the past three decades (Exhibit 6-2). There are variations in trends in forest cover among the different EPA Regions. For example, between 1907 and 2002, forest land declined by roughly 22 million acres in Region 6 and more than 12 million acres in Region 9. Over the same period, forest land increased by 13 million acres in Region 3 and by 10 million acres in Region 5.

In addition to changes in the extent of forest, there have been changes in the types of forests over time (Exhibits 6-3 and 6-4). The largest changes in the eastern U.S. over the 1953-2002 period occurred in the maple-beech-birch forest type and the oak-hickory forest type, which gained 27.5 million acres and 23 million acres, respectively, since 1953. In the West, the fir-spruce type and Western hardwood type also have increased (about 11.5 million acres each) since 1953, while the hemlock-Sitka spruce, pinyon-juniper, and ponderosa-Jeffrey pine forest types have decreased by about 13.6 million, 8.8 million, and 8.7 million acres respectively. The Western white pine forest type has decreased by 5.3 million acres, or about 96 percent of its 1953 acreage.

Indicator Limitations

- Data on extent of forest land have an uncertainty of 3 to 10 percent per million acres for data reported since 1953. In 1998 Congress mandated that the FIA move to annual inventories. While data now are collected more often, fewer data are collected in any given year. Because area estimates now are based on a smaller sample size, the precision of the national estimates may be reduced relative to pre-1998 dates.
- Most of the specific data related to species and age classes are only collected on lands classified as timberland and not forest land in general.

INDICATOR | Forest Extent and Type (continued)

- In addition to extent and species class, age class also influences the use of forest land as habitat by different species. Younger and older stands of forest have increased over the past half-decade, while middle-aged stands of more merchantable timber have decreased (Smith et al., 2001, 2004).

Data Sources

This indicator is based on data from two USDA Forest Service reports (Smith et al., 2001, 2004), which provide current and historical data on forest extent and type by state. Most data were obtained from the 2004 report; the 2001 report was consulted only for 1963 data, which were excluded from the more recent report. Data were originally collected by the USDA Forest Service's FIA program; original survey data are available from the FIA database (USDA Forest Service, 2005) (http://www.fia.fs.fed.us/tools-data/).

References

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. Forest resources of the United States, 2002. General Technical Report NC-241. St. Paul, MN: USDA Forest Service, North Central Research Station. <http://ncrs.fs.fed.us/pubs/gtr/gtr_nc241.pdf>

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INDICATOR | Forest Fragmentation

The amount of forest land in the U.S. monitored by the U.S. Department of Agriculture (USDA) Forest Service has remained nearly constant over the past century, but the patterns of human land use have affected its distribution from one region of the U.S. to another. Forest fragmentation involves both the extent of forest and its spatial pattern, and is the degree to which forested areas are being broken into smaller patches and pierced or interspersed with non-forest cover.

Forest fragmentation is a critical aspect of the extent and distribution of ecological systems. Many forest species are adapted to either edge or interior habitats. Changes in the degree or patterns of fragmentation can affect habitat quality for the majority of mammal, reptile, bird, and amphibian species found in forest habitats (Fahrig, 2003). As forest fragmentation increases beyond the fragmentation caused by natural disturbances, edge effects become more dominant, interior-adapted species are more likely to disappear, and edge- and open-field species are likely to increase.

This indicator of forest fragmentation was developed by the USDA Forest Service. The indicator is based on the 2001 National Land Cover Database (NLCD), which was constructed from satellite imagery showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) around the year 2001 (Homer et al., 2007). The USDA Forest Service's Southern Research Station performed a re-analysis of the NLCD, aggregating the four NLCD forest cover classes (coniferous, deciduous, mixed, and wetland forest) into one forest class and the remaining land cover classes into a single non-forest class (USDA Forest Service, 2007). A model that classifies forest fragmentation based on the degree of forest land surrounding each forest pixel (a square approximately 30 meters on each edge) for various landscape sizes (known as "windows") provides a synoptic assessment of forest fragmentation for the contiguous U.S. by assessing each pixel's "forest neighborhood" within various distances.

Results are based on four degrees of forest cover: "core" if a subject pixel is surrounded by a completely forested landscape (no fragmentation), "interior" if a subject pixel is surrounded by a landscape that is 90 to 100 percent forest, "connected" if a subject pixel is surrounded by a landscape that is 60 to 90 percent forest, and "patchy" if the subject pixel is surrounded by less than 60 percent forest. The window (landscape) size used for this analysis was 13 by 13 pixels, 390 meters on each edge, or about 15.2 hectares (37.6 acres). The window is shifted one pixel at a time over the map, so the target population for the indicator is all forested pixels in the contiguous U.S. Percent forest was resampled from 30-meter pixel data and aggregated by state to develop the EPA Region-specific breakouts.

What the Data Show

Slightly more than 26 percent of the forested pixels in the U.S. represent "core" forest, i.e., landscapes dominated by forest (Exhibit 6-5). However, the data for "interior" and "core" forests suggest that fragmentation is extensive, with few large areas of complete, unperforated forest cover. About 19 percent of forest pixels in the U.S. occur in a landscape where less than 60 percent of the "neighborhood" is forest (i.e., forest cover is "patchy").

There is considerable regional variation in forest fragmentation (Exhibit 6-5). Regions 1, 2, and 3 have more than 30 percent "core" forest pixels, while fewer than 20 percent of the forest pixels in Region 7 are "core" forest. From the opposite perspective, fewer than 10 percent of forest pixels in

Region 1 are surrounded by less than 60 percent forest, compared to almost 40 percent of the forest pixels in Region 7.

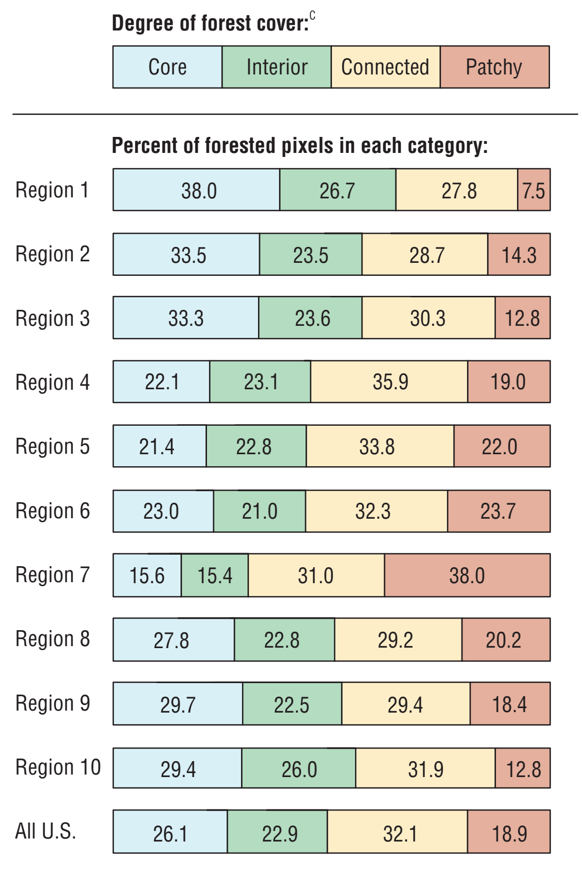
Indicator Limitations

- Trend information is not available for this indicator. Although earlier land cover data are available as part of the 1992 NLCD, they are not directly comparable with the 2001 NLCD due to differences in classification methodology. Efforts to compare these two products are ongoing.
- The apparent degree of connectivity depends on the size of the window. In a similar analysis of 1992 NLCD data, Riitters (2003) determined that the percentages for all categories (especially "core" and "connected" forest pixels) decrease rapidly as the size of the window is increased progressively from 18 to 162, 1,459, and 13,132 acres.
- Because the non-forest land cover classes were aggregated, this indicator does not distinguish between natural and anthropogenic fragmentation (although such a distinction has been made for global fragmentation by Wade et al., 2003).
- The data do not include Hawaii or Alaska, which account for about 1 out of every 6 acres of forest land in the U.S.

Data Sources

An earlier version of this analysis was published in Riitters (2003) and Heinz Center (2005). The analysis presented here has not yet been published; data were provided by the USDA Forest Service (2007), and EPA grouped the results by EPA Region. This indicator is based on land cover data from the 2001 NLCD (MRLC Consortium, 2007).

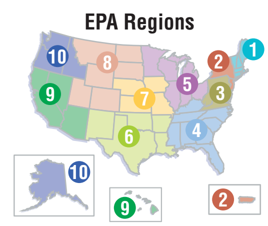
Exhibit 6-5. Forest fragmentation in the contiguous U.S. by EPA Region, based on 2001 NLCD[a,b]



[a]**Coverage:** Areas of the contiguous 48 states classified as "forested" by the 2001 National Land Cover Database (NLCD).

[b]Totals may not add to 100% due to rounding.

[c]See text for definitions of forest cover categories.



Data source: *USDA Forest Service, 2007*

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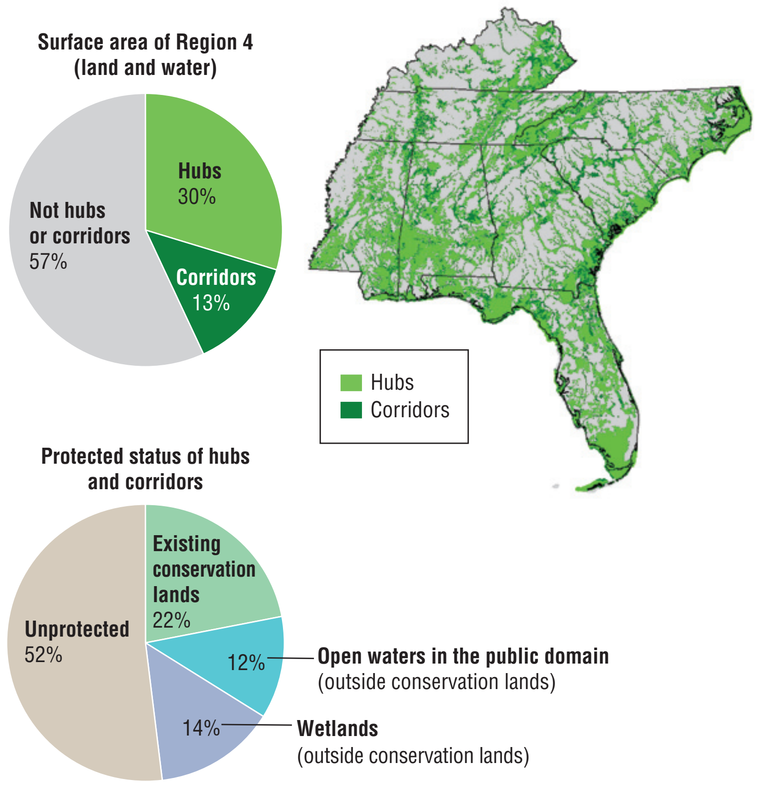
INDICATOR | Ecological Connectivity in EPA Region 4

As part of their natural functioning, ecological systems remove particulate matter and carbon dioxide from the air, purify surface and ground water, reduce flooding, and maintain biological diversity. These functions depend on a connected ecological "framework" of high-quality land consisting of central hubs interconnected by corridors that provide for the movement of energy, matter, and species across the landscape. This framework of connectivity is threatened by agricultural and silvicultural practices, road development, and "urban sprawl" that fragment the landscape. Maintaining ecological connectivity protects the entire system.

The Ecological Connectivity Indicator (ECI) developed by EPA Region 4 (Durbrow et al., 2001) consists of a framework that captures the connectivity of important natural areas and ecological systems across the landscape of the Region (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee). Four ecological aspects contribute to the functionality of the ECI infrastructure (see Carr et al., 2002, for additional details). The most important of the four, hub and corridor connectivity, forms the basis for this indicator. Hub and corridor connectivity shows the connections among critical ecological systems in the Region. Hubs are large areas of important natural ecosystems such as the Okefenokee National Wildlife Refuge in Georgia and the Osceola National Forest in Florida. Connections, referred to as "corridors," are links to support the functionality of the hubs (e.g., the Pinhook Swamp which connects the Okefenokee and Osceola hubs). The ECI framework is based on land cover data obtained from the 1992 National Land Cover Dataset (NLCD), which was constructed from satellite imagery (Landsat) showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) during the early 1990s. In many locations, the best available Landsat images were collected between 1991 and 1993, with data in a few locations ranging from 1986 to 1995.

Exhibit 6-6. Ecological hubs and corridors in EPA Region 4, based on 1992 NLCD



Data source: *U.S. EPA, 2002*

What the Data Show

The hub and connection framework covers 43 percent of the total land and water resources in EPA Region 4—30 percent classified as hubs and 13 percent as corridors (Exhibit 6-6). Currently, 22 percent of this framework area is protected as conservation land, 12 percent is in the public domain as open water, and an additional 14 percent is classified as wetlands, for a total of 48 percent of hub and corridor acreage being afforded some type of long-term protection.

Indicator Limitations

- Trend information is not available for this indicator. The most important data layer used in the ECI development is the NLCD from the early 1990s. Establishing trends in the indicator may be limited by the availability of comparable land cover/land use data in the future.
- Due to both the limited availability of data (ecological data not available or not in digital or geographic information system [GIS] format) and the Southeastern Ecological Framework (SEF) parameter that sets a size threshold of 5,000 acres for ecological hubs, the results do not comprehensively include each and every ecologically important area in the Southeast. The appropriate geographic scale of connectivity depends on the species and communities that are the focus of particular protection efforts (Carr et al., 2002).

INDICATOR | Ecological Connectivity in EPA Region 4 *(continued)*

Data Sources

The hub and corridor map was provided by EPA Region 4's SEF project, and is available as a GIS data layer from the SEF Web site's data page (U.S. EPA, 2002) (http://geoplan.ufl.edu/epa/data.html). The summary statistics shown in the pie charts in Exhibit 6-6 are presented in Carr et al. (2002). This analysis was based on the 1992 NLCD (USGS, 2005) (http://landcover.usgs.gov/natllandcover.php) and several additional datasets described in Carr et al. (2002); input data layers can be obtained on CD by following instructions on the SEF Web site (U.S. EPA, 2002).

References

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INDICATOR | Relative Ecological Condition of Undeveloped Land in EPA Region 5

Ecological condition in the ROE is approached using questions broadly relating to landscape, biological diversity, ecological function, and the physical and chemical makeup of the environment, but no attempt is made at the national level to capture ecological condition in a small number of indices. In this indicator, the ecological condition of undeveloped land in EPA Region 5 (Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin) is characterized based on three indices derived from criteria representing diversity, self-sustainability, and the rarity of certain types of land cover, species, and higher taxa (White and Maurice, 2004). In this context, "undeveloped land" refers to all land use not classified as urban, industrial, residential, or agricultural.

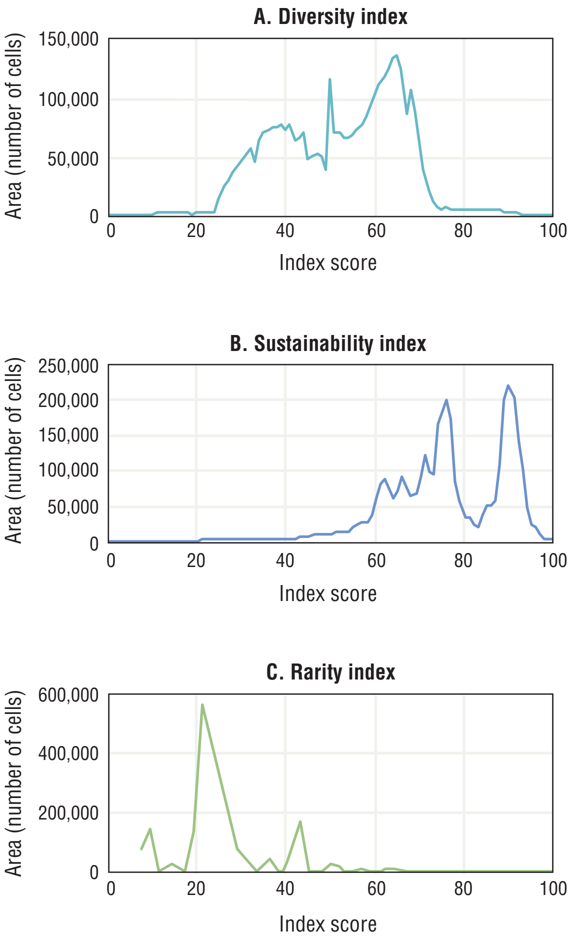
Geographic units referred to as cells are used to quantify geographic information. A spatially explicit model using ecological theory and geographic information system (GIS) technology was used to create 20 data layers of 300-meter by 300-meter cells. These layers originate from several sources, including water quality datasets, state Natural Heritage Program databases (for species abundance), and the 1992 National Land Cover Dataset (NLCD), which was constructed from satellite imagery (Landsat) showing the land area of the contiguous U.S. during different seasons (i.e., leaves-on and leaves-off) during the early 1990s. In many locations, the best available Landsat images were collected between 1991 and 1993, with data in a few locations ranging from 1986 to 1995. For this indicator, data layers were combined to generate three indices, which represent estimates of three criteria:

- **Ecological diversity.** The relative diversities of populations (species), communities, and ecological systems in any given location on the landscape. Four data layers were used to derive this index.
- **Ecological self-sustainability.** The potential for an ecological system to persist for years without external management; it is negatively impacted by two factors: landscape fragmentation and the presence of chemical, physical, and biological stressors. Twelve data layers were used to derive this index.
- **Rarity.** The rarity of land cover, species, and higher taxa. Four data layers were used to derive this index.

The model produces composite layers that are statistically independent. The scores for each criterion are normalized from 1 to 100 and each layer contributes equally to the final index (all of the data layers are weighted equally). In all the data layers and the resultant criteria layers, scores are normalized from 0 to 100. Zero always indicates the lowest quality, the greatest stress, or the least valuable observation, and 100 indicates the highest quality, least stress, or most valuable observation. While

INDICATOR | Relative Ecological Condition of Undeveloped Land in EPA Region 5 *(continued)*

Exhibit 6-7. Distribution of index scores for the relative ecological condition of undeveloped land in EPA Region 5, 1990-1992[a]



[a]**Coverage:** Undeveloped land in EPA Region 5, based on the 1992 National Land Cover Dataset (NLCD). For this analysis, "undeveloped" land is any land that the NLCD classifies as bare rock/sand/clay, deciduous forest, evergreen forest, mixed forest, shrubland, grasslands/herbaceous, woody wetlands, emergent herbaceous wetlands, or open water.

Data source: *U.S. EPA, 2006*

it has not been done for this indicator, the three composite scores can be summed to result in a final "ecological condition" score for each cell (White and Maurice, 2004). Cell counts (a measure of geographic coverage) are used to indicate the distributions of scores associated with three index scores of ecological condition of undeveloped land: diversity, sustainability, and rarity.

What the Data Show

The frequency distributions of the 1992 baseline scores are quantified and plotted for each criterion (Exhibit 6-7), and these provide a baseline against which to track future landscape trends in diversity, sustainability, and rarity. Diversity scores generally run from 20 to 80 across the region, signifying that most areas are in the moderate diversity range. More than 90 percent of the region has sustainability scores above 50, but rarity scores above 50 are seldom encountered. The highest index scores are found largely in the northern forests of Minnesota, Wisconsin, and Michigan and along the large rivers in Ohio, Indiana, and Illinois (Exhibit 6-8).

Indicator Limitations

- Trend information is not available for this indicator. Establishing trends in the indicator may be limited by the availability of comparable land cover/land use data in the future.
- Although this indicator is designed to be comparable across undeveloped land within Region 5, layers were ranked within ecoregions for some of the components in order to account for different geophysical, geochemical, or climatic features of each ecoregion.
- Aquatic systems and connectivity resulting from water flow paths are not adequately covered and small, but potentially keystone, systems are not a part of the analysis (U.S. EPA, 2005).
- The data layers that contribute to each index were weighted equally, which may not reflect the actual relative importance of each layer (U.S. EPA, 2005).
- The resolution and uncertainty of the results make comparing the ecosystem condition score for one individual cell (300 meters by 300 meters) with another inappropriate, but this is not the case for comparison

INDICATOR | Relative Ecological Condition of Undeveloped Land in EPA Region 5 *(continued)*

between larger landscapes (U.S. EPA, 2005).

- The model has not yet been field-validated to ensure that modeled results reflect actual ecosystem condition.

Data Sources

Maps and frequency distributions for the three indices were provided by EPA Region 5 (U.S. EPA, 2006). An EPA report available online contains several related maps produced by the Critical Ecosystem Assessment Model (CrEAM), along with a list of the various data-sets used as inputs for the model (White and Maurice, 2004, appendices). Results from the CrEAM model are no longer available as digital map layers.

References

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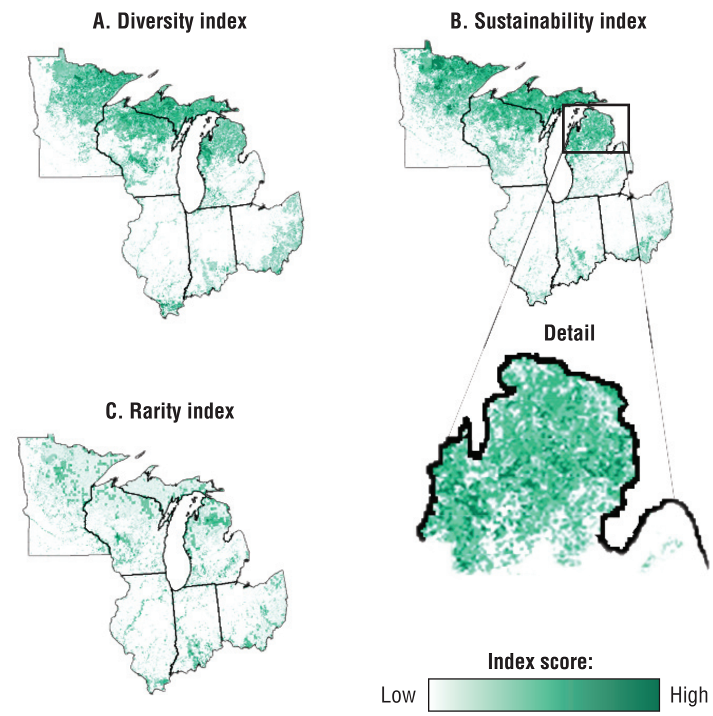
White, M.L., and C. Maurice. 2004. CrEAM: A method to predict ecological significance at the landscape scale. Chicago, IL: U.S. Environmental Protection Agency.

Exhibit 6-8. Relative ecological condition of undeveloped land in EPA Region 5, 1990-1992[a]



[a]**Coverage:** Undeveloped land in EPA Region 5, based on the 1992 National Land Cover Dataset (NLCD). For this analysis, “undeveloped” land is any land that the NLCD classifies as bare rock/sand/clay, deciduous forest, evergreen forest, mixed forest, shrubland, grasslands/herbaceous, woody wetlands, emergent herbaceous wetlands, or open water.

Data source: *U.S. EPA, 2006*

6.2.3 Discussion

What These Indicators Say About Trends in Extent and Distribution of the Nation’s Ecological Systems

While ecological systems are interconnected and overlapping, it is useful to discuss trends in terms of major types of systems. As previously mentioned, there are many ways to define ecological systems, including by the predominant biota, spatial scales, and physical characteristics. Most terrestrial systems are defined by predominant vegetation types. The current extent of these types has been assessed (see the Land Cover indicator, p. 4-7). Forests form the predominant land cover in the eastern and northwestern U.S. while grasslands, shrublands, and agricultural lands are the predominant types of vegetation in the central and western parts of the country. Trends in forest and wetland ecological systems are considered below. Trends in land development also are discussed, as this influences trends in the extent of ecological systems.

Trends in Extent and Distribution of Forested Ecological Systems

At a national scale, the percentage of forest land has varied somewhat over the last century with some decreases and some recent increases (see the Forest Extent and Type indicator, p. 6-8). Over the same period, shifts in regional distribution and species composition have occurred. For example, forested ecological systems decreased in extent in EPA Regions 6 and 9 over the last century, but increased in extent in Regions 1, 2, 3, and 5. The complex of tree species within a forest can have a strong influence on the community structure and functioning of a forested ecological system, and these assemblages can change over time. On a broad geographic scale, some forest types have more than doubled in acreage in the last 50 years—for example, maple-beech-birch in the eastern U.S. and fir-spruce in the West. At the same time, some other types of forest have decreased in acreage. These compositional changes can be as important as changes in the overall extent of forested ecological systems.

At a finer regional scale, forest cover in the Puget Sound and Georgia Basin in the Pacific Northwest also was relatively stable during the 1990s (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10). However, some of the forested watersheds experienced a conversion of small amounts of forest land to some other cover type. As discussed below, urbanization of low-elevation forested watersheds is a change that is receiving particular attention (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10).

While extent and species composition are important aspects of forested ecological systems, the spatial arrangement and contiguity of the systems also influence the functioning of the systems and the distribution of wildlife species that use forests and adjacent areas for habitat. Fragmentation of forested systems can reduce or redefine the interconnections within forests, modifying the scale of habitat and shifting distributions of wildlife species. For example, increasing fragmentation due to forest clearing, development, fires, or other activities creates more edge habitat and limits the acreage of interior habitat. Groups of wildlife species may prefer one habitat over another and move to maximize the time spent in the preferred habitat type. Nationwide, almost one-fifth of forests are highly fragmented or "patchy," although more than 30 percent of the forests in the heavily forested Regions 1, 2, and 3 are virtually unfragmented "core" forest (see the Forest Fragmentation indicator, p. 6-11).

Ecosystem connectivity, characterized by ecosystem "hubs" connected to each other by "spokes" that serve as corridors for the interaction of biota, was shown to account for about 40 percent of the land cover in EPA Region 4, the southeastern U.S. (see the Ecological Connectivity in Region 4 indicator, p. 6-13). In this indicator, connectivity includes not only forested land but also wetlands and open water.

Trends in Extent and Distribution of Wetland Ecosystems

Wetlands are ecosystems of high biological diversity and support a number of ecological functions from nursery and breeding areas to food and protection.[16] Whether inland or coastal, freshwater or marine, wetland acreage has declined over the past 50 years (see the Wetlands indicator, p. 3-32). The extent of the losses varies by type of wetland, with forested wetlands losing the most acreage and coastal wetland loss slowing somewhat.

Trends in Land Development

"Land use" refers to the visible effects of human use (see the Land Use indicator, p. 4-14). Changes in land use from forested or wetland systems to urban or agricultural environments have a direct impact on the ecological systems within which the change occurs, as well as on systems that are interconnected with the altered areas (e.g., watersheds and coastal areas). Some changes can create edge environments that are favored by certain wildlife species. Therefore, trends in land development are important considerations with respect to overall trends in the extent and distribution of ecological systems.

Changes in land use sometimes result in changes in land cover and conversion from one major ecosystem type to another, but sometimes they do not. For example, gains in agricultural productivity have caused significant changes in the extent and location of crop and pasture land uses. Some land that had been used for crops or pasture has reverted to forest. Timber production may convert cropland to forest, or it may do little more than substitute one forest type or age-class distribution for another. At the same time, growth in population has driven an increase in the extent of developed land, much of which has converted crop or pasture land to developed land.

At a national scale over the last three decades, crop and farm acreages have decreased, timberland (productive forest land) has remained fairly constant, and developed lands have increased (see the Land Use indicator, p. 4-14). Within the larger-scale trends, many subtle shifts occur at smaller scales. The increase in developed lands has received particular attention in National and Regional Indicators.

Increases in the numbers and changes in the spatial distribution of human populations explain part of the increase in developed lands. However, developed land increased by almost two times the increase in population from 1982 to 2003, suggesting that during this period people were making a proportionally greater use of the landscape (see the Urbanization and Population Change indicator, p. 4-19). Geographically, the rate of development was four times the population growth rate in the Northeast, one to three times the population growth rate in the South and Midwest, and nearly equal to the growth rate in the West. The increases in developed land suggest there were comparable decreases in other types of lands. To the extent that these other lands afford habitat to animals and plants, shifts in land use result in shifts in the extent and distribution of ecological systems. Increases in developed land also impact physical and chemical factors; for example, more runoff from impervious surfaces leads to greater loading of nutrients and contaminants, more unstable hydrology, reduced ground water inputs, and increased stream temperatures.

The degree of change in developed lands appears to be associated with types of locations that emerge as focal points for increasing stress on ecological systems. For example, in the Puget Sound and Georgia Basin area of the Pacific Northwest,

[16] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. Washington, DC: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

forest conversion to other types of land use is occurring along the coast while older growth forests are observed at higher elevations (see the Land Cover in Puget Sound/Georgia Basin indicator, p. 4-10). Further, trends indicate that impervious surface coverage is increasing to the point where detrimental impacts to aquatic resources may occur.[17] In the Great Lakes region, most of the undeveloped lands occur in the northern forests or along the major rivers (see the Condition of Undeveloped Land in Region 5 indicator, p. 6-14). Proximity to developed areas has an obvious effect on the quality of these ecological systems. The highest quality systems make up about 3 percent of the total and are located in the most remote and/or protected areas.

Limitations, Gaps, and Challenges

While many of the indicators in this section provide baseline information, trend information is available for only a few of the major types of systems—forests and wetlands. There are no ROE indicators for other types of terrestrial or aquatic systems including grasslands, shrublands, and marine hard bottom communities such as coral reefs, or for finer-scale ecosystem classifications such as riparian zones or habitat for threatened and endangered species. Filling these gaps in information would help EPA to better evaluate trends in ecological condition.

One of the challenges in capturing meaningful changes relates to location and scale. The importance of location-specific changes is evident in some of the indices. For example, small changes in certain areas, such as near-coastal areas of the Pacific Northwest, could have disproportionately large effects on coastal waters relative to a similar change in the middle of an expansive prairie. In addition, the appearance of fragmentation in ecological systems depends on the area over which data were extracted.[18] Thus, choosing locations and assessment areas have obvious impacts on trend assessment. Conversely, the implications of trends are manifested at scales that are location- and area-specific. Important consequences of changes can be captured or missed depending on how the information is aggregated and presented.

Another challenge relates to understanding the factors underlying changes that occur over various time scales and their effects on human health and ecological condition. Principal among these is recognizing that natural cycles and natural variability bring about changes that may appear as "trends" over one time scale but will appear as cycles or variations over longer time scales. Familiar examples include population variations among predators and prey or temperature variations associated with the advance and retreat of ice ages. Distinguishing these natural cycles and variations from trends caused by human-induced perturbations is yet another challenge. In some cases the relationships may be evident, as in the influence of urbanization on watersheds or the impact of lost sand dunes on subsequent beach erosion. In other cases factors influencing changes may be difficult to discern, such as long-term shifts in major plant communities.

6.3 What Are the Trends in the Diversity and Biological Balance of the Nation's Ecological Systems?

6.3.1 Introduction

Trends in the biological diversity of the nation's ecological systems can be viewed in terms of both the numbers of species present in an ecological system and the extent to which some of the species are threatened or endangered. "Biological balance" refers to the interrelationships among organisms, including the structure of food webs and the ability of ecological systems to maintain themselves over time. Balance is a dynamic characteristic rather than a fixed state.

The biological diversity and balance within ecological systems are often used to judge the health of the system, and their reduction often represents a response to pollutants or other stressors. Restoring biodiversity and biological balance has been a focus of EPA's attention over the past three decades. Reversing declines of species such as the brown pelican (caused by pesticides) and brook trout (caused by acid rain), replacing nuisance algal blooms caused by excess nutrients with balanced communities of phytoplankton, replacing beds of sludge worms below wastewater discharges with balanced communities of benthic invertebrates, and restoring biological communities previously decimated by improper handling of toxic and hazardous wastes are well-known examples.

The significance of biological diversity also stems from the fact that, for many people, biological diversity contributes to the quality of life.[19] Everyone recognizes the importance of species as commodities (if those species produce products that can be bought and sold), and some argue that species have moral value in and of themselves.

Diversity and biological balance are also of interest because of how they may influence the functioning and stability of ecological systems.[20,21] While scientists debate the exact relationship between the diversity and the functioning and

[17] Klein, R.D. 1979. Urbanization and stream water quality impairment. Water Resour. Bull. 15(4):948-963.

[18] USDA Forest Service. 2004. National report on sustainable forests—2003. <http://www.fs.fed.us/research/sustain/>

[19] Norton, B. 1988. Commodity, amenity, and morality: The limits of quantification in valuing biodiversity. In: Wilson, E.O., ed. Biodiversity. Washington, DC: National Academies Press.

[20] Chapin III, F.S., B.H. Walker, R.J. Hobbs, D.U. Hooper, J.H. Lawton, O.E. Sala, and D. Tilman. 1997. Biotic control over the functioning of ecosystems. Science 277(5325):500-504.

[21] Wilson, E.O. 1992. The diversity of life. Cambridge, MA: Belknap Press.

stability of ecological systems, it is generally agreed that as the number of species in any particular type of ecological system declines, there is a potential loss of resilience within that system.[22] It is also recognized that these relationships are not straightforward and can vary in degree depending on the types of species introduced to or removed from a system.[23]

Diversity and balance have important time and space components. Diversity arises over time as adaptation results in new species that fill available niches in the environment. This is a dynamic process involving colonization, evolution of species adapted to new conditions, and extinction of species that are less well adapted to a changing environment. This process has occurred over thousands or millions of years over large geographic areas, punctuated occasionally by events such as large meteor impacts, periods of intense volcanism, and ice ages. Ecological systems that are stable in the short term evolve into different systems in the long term. Disturbances that reduce biological diversity or disrupt balance on a small scale may not have an effect on a larger scale or over longer time periods.

Changes (decreases and increases) in biological diversity have likely occurred throughout the history of the U.S. in response to regional land use changes, water management, intentional and unintentional introductions of species, and environmental pollution. Other changes in diversity and the composition of the biological community can be rapid and dramatic. Introduced plants and plant pathogens can rapidly transform landscapes as some species, such as the American chestnut, are lost and others, such as kudzu, thrive. Introduction of the sea lamprey to the Great Lakes led to sweeping changes in the entire food chain, from lake trout all the way down to the phytoplankton.[24] Declining sea otter populations led to loss of kelp forests, as sea urchins formerly preyed upon by otters grazed the kelp down to the sea floor.[25] The decimation of grazers such as the American Bison or predators such as grizzly bear or wolves has had cascading impacts on upland vegetation, wetlands, fish, and other species.[26] Toxic chemical pollution can create wastelands where only the most resistant species can survive, and nutrients and acid rain have had indirect effects on diversity and balance by causing sweeping changes in the chemical habitat.

Indicators of diversity and biological balance incorporate information about primary producers and invertebrate and vertebrate consumers, especially keystone species that play critical roles in structuring habitat or serve major roles as primary producers, top predators, or important prey species. Indicators of invasive species are also important with respect to assessing trends in diversity and biological balance because these species can alter the nation's ecological systems by displacing indigenous species, potentially changing the structure of biological communities.

6.3.2 ROE Indicators

Trends in diversity and balance are evaluated using four National Indicators and two Regional Indicators (Table 6-3). The focus for this question is on national- or regional-scale trends in biological diversity or balance over time spans of one to three decades. The data on biological diversity and

Table 6-3. ROE Indicators of Trends in Diversity and Biological Balance of the Nation's Ecological Systems

National Indicators	Section	Page
Coastal Benthic Communities (N/R)	3.5.2	3-44
Benthic Macroinvertebrates in Wadeable Streams	3.2.2	3-21
Bird Populations	6.2.2	6-20
Fish Faunal Intactness	6.2.2	6-21
Regional Indicators	**Section**	**Page**
Submerged Aquatic Vegetation in the Chesapeake Bay	3.5.2	3-46
Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest	6.2.2	6-23

N/R = National Indicator displayed at EPA Regional scale

22 McCann, K.S. 2000. The diversity-stability debate. Nature 405(11):228-233.

23 Srivastava, D.S., and M. Vellend. 2005. Biodiversity-ecosystem function research: Is it relevant to conservation? Annu. Rev. Ecol. Syst. 36:267-294.

24 Eck, G.W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (Alosa pseudoharengus). Can. J. Fish. Aquat. Sci. 44(Suppl. 2):53-60.

25 Estes, J.A., and J.F. Palmisano. 1974. Sea otters: Their role in structuring nearshore communities. Science 185:1058-1060.

26 Pritchard, J.A. 1999. Preserving Yellowstone's natural conditions: Science and the perception of nature. Lincoln, NE: University of Nebraska Press.

balance come from a variety of sources, including both systematic monitoring and ad hoc data collection.[27] Systematic probability surveys are now providing national pictures of the biological diversity of benthic communities in estuaries and in rivers and streams. The Breeding Bird Survey is a private sector effort that provides valuable national-level data on trends in bird populations.

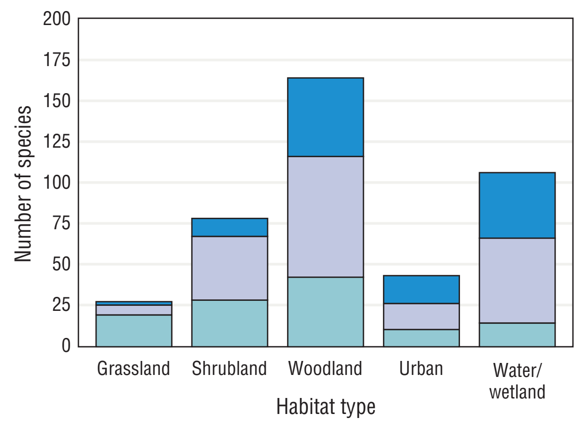
Trends involving longer-term effects associated with climate change are not included. Many issues regarding biodiversity at subregional and local scales (e.g., tall-grass prairie or the Okefenokee Swamp) that cannot be covered here are no less important.

INDICATOR | Bird Populations

Bird populations are among the most visible biological components of ecological systems, supporting a number of important ecological functions including seed dispersal, plant pollination, and pest control. Some birds migrate over entire continents, while others have more restricted ranges and habitats, but in all cases trends in bird populations and in the abundance of species integrate the influences of changes in landscape and habitat, the availability and quality of food, toxic chemicals, and climate. The North American Breeding Bird Survey (BBS) began in 1966 with approximately 600 surveys conducted in the U.S. and Canada east of the Mississippi River. Today there are approximately 3,700 active BBS routes across the continental U.S. and southern Canada (Sauer et al., 1997).

Trends have been computed for observed population sizes of 418 bird species for the 1966-2003 period (Sauer et al., 2004). The Audubon Society (2004) categorized each species according to its primary habitat: grassland, shrubland, woodland, urban, and water and wetlands. This indicator reflects the number of species with “substantial” increases or decreases in the number of observations (not a change in the number of species) for which adequate trend data exist between 1966 and 2003. Substantial increases or decreases were defined for this study as those in which the observed populations on BBS routes increased or decreased by more than two-thirds between 1966 and 2003; this designation does not necessarily imply a statistically significant trend.

Exhibit 6-9. Changes in bird populations in the contiguous U.S. and southern Canada, by habitat type, 1966-2003[a]



[a]**Coverage:** 418 bird species studied as part of the North American Breeding Bird Survey (BBS), which covers the contiguous U.S. and southern Canada.

[b]Increases or decreases are considered “substantial” if the observed population on BBS routes increased or decreased by more than two-thirds from 1966 to 2003.

Data source: *Audubon Society, 2004*

What the Data Show

The results point to dynamic changes in observed bird populations in all habitat types (Exhibit 6-9), although there were no consistent increases or decreases.

- Of 27 grassland species for which adequate data are available, only two species (7 percent) showed substantial observed population increases and 19 species (70 percent) showed substantial decreases.
- Of 78 shrubland species for which adequate data are available, 11 species (14 percent) showed substantial increases, while 28 species (36 percent) showed substantial declines.
- Of 164 woodland species for which adequate data are available, 48 species (29 percent) showed substantial observed population increases and 42 species (26 percent) showed substantial decreases.
- Of 43 primarily urban species for which adequate data are available, 17 species (40 percent) showed substantial observed population increases and 10 species (23 percent) had substantial decreases.
- Of 106 water and wetland bird species for which adequate data are available, 40 species (38 percent) showed substantial observed population increases and 14 species (13 percent) showed substantial decreases.

Indicator Limitations

- The BBS produces an index of relative abundance rather than a complete count of breeding bird populations. The

[27] There are no systematic national efforts to quantify trends in the diversity of other vertebrate, invertebrate, plant, or microbial species, but a private sector organization, NatureServe, working in concert with state Natural Heritage Programs, has done much to assimilate and integrate data from ad hoc and systematic studies to assess the status of nearly 40,000 U.S. species and to quantify populations of more than 20,000 at-risk species.

INDICATOR | Bird Populations *(continued)*

data analyses assume that fluctuations in these indices of abundance are representative of the population as a whole.

- The BBS data do not provide an explanation for the causes of observed population trends. To evaluate population changes over time, BBS indices from individual routes are combined to obtain regional and continental estimates of trends. Although some species have consistent trends throughout the history of the BBS, most do not. For example, populations of permanent resident and short-distance migrant species (birds wintering primarily in the U.S. and Canada) are adversely affected by periodic episodes of unusually harsh winter weather.
- Few species have consistent observed population trends across their entire ranges, so increases or decreases in this indicator may not reflect the situation across the entire range of the species.

Data Sources

Trend data were obtained from the Audubon Society's 2004 *State of the Birds* report (Audubon Society, 2004). Audubon's analysis used raw data from the National Breeding Bird Survey (USGS, 2004), which can be downloaded from http://www.pwrc.usgs.gov/bbs/retrieval/menu.cfm.

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Sauer, J.R., J.E. Hines, and J. Fallon. 2004. The North American Breeding Bird Survey, results and analysis 1966-2003. Version 2004.1. Laurel, MD: USGS Patuxent Wildlife Research Center. <http://www.mbr-pwrc.usgs.gov/bbs/bbs.html>

Sauer, J.R., J.E. Hines, G. Gough, I. Thomas, and B.G. Peterjohn. 1997. The North American Breeding Bird Survey, results and analysis. Version 96.4. Laurel, MD: USGS Patuxent Wildlife Research Center. <http://www.mbr-pwrc.usgs.gov/bbs/genintro.html>

USGS (United States Geological Survey). 2004. North American Breeding Bird Survey. Laurel, MD: USGS Patuxent Wildlife Research Center. Accessed 2004. <http://www.pwrc.usgs.gov/bbs/index.html>

INDICATOR | Fish Faunal Intactness

Intactness, the extent to which ecological communities have retained their historical composition, is a critical aspect of the biological balance of the nation's ecological systems (NRC, 2000). It is of particular importance in freshwater systems that are impacted by pollution, habitat alteration, fisheries management, and invasive species.

This indicator tracks the intactness of the native freshwater fish fauna in each of the nation's major watersheds by comparing the current faunal composition of those watersheds with their historical composition. In this case, historical data are based on surveys conducted prior to 1970. The indicator specifically measures the reduction in native species diversity in each 6-digit U.S. Geological Survey hydrologic unit code (HUC) cataloguing unit in the 48 contiguous states. Intactness is expressed as a percent based on the formula:

$$\textit{reduction in diversity} = 1 - \left(\frac{\textit{\# of current native species}}{\textit{\# of historical native species}}\right)$$

The native species diversity indicator proposed by the National Research Council (NRC, 2000) compared expected native species diversity (projected from species-area-curve models) with observed diversity. This "Fish Faunal Intactness" indicator makes use of empirical, rather than modeled, data sets and focuses on a well-known group of organisms with a fairly strong historical record.

Reductions in watershed diversity may be due either to the overall extinction of a species (at least 12 U.S. freshwater fish species are known to be extinct and another three species are known only from historical records and may be extinct) or, more commonly, to the extirpation of a species from selected watersheds. In the case of regional extirpations, opportunities may exist for restoring a species to watersheds in its historical range.

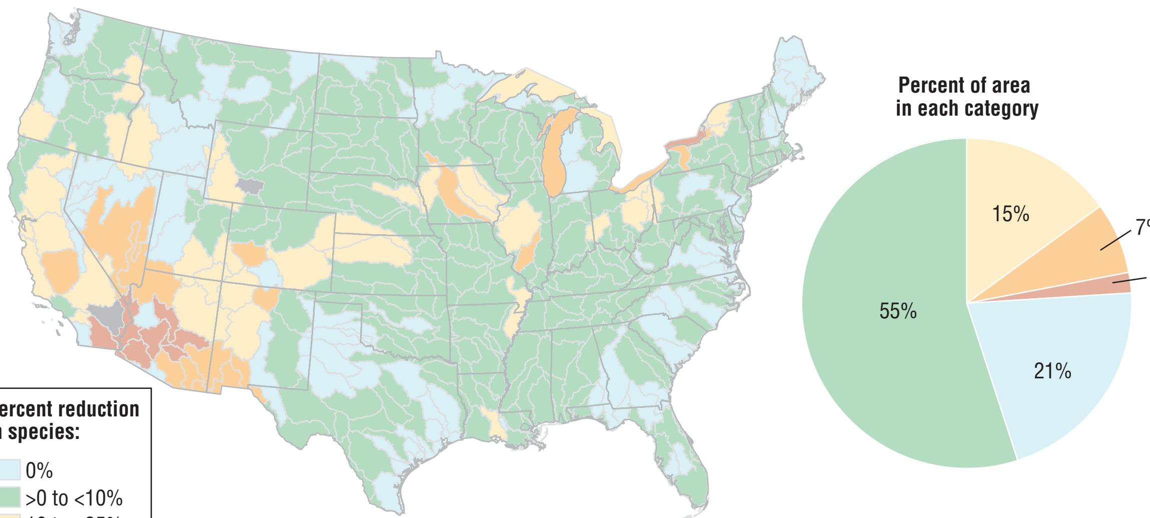
The fish distributional data underlying this indicator were gathered by NatureServe, a nonprofit research organization, and are derived from a number of sources, including species occurrence data from state Natural Heritage Programs, a broad array of relevant scientific literature (e.g., fish faunas), and expert review in nearly every state. These data were assembled during the 1997-2003 period. The underlying data include distributions for 782 native freshwater fish species across small watersheds (8-digit HUC). For this indicator, data were pooled and reported by larger 6-digit HUCs to reduce potential errors of omission in the smaller watersheds.

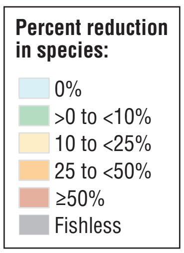
What the Data Show

Watersheds covering about one-fifth (21 percent) of the area of the contiguous U.S. appear to have fish faunas that are fully intact, retaining the entire complement of

INDICATOR | Fish Faunal Intactness *(continued)*

Exhibit 6-10. Percent reduction in native fish species diversity in the contiguous U.S. from historical levels to 1997-2003[a]





[a]Data are displayed by 6-digit hydrologic unit code (HUC) watershed. Percent reduction is based on the number of native species present during the period 1997-2003, compared with historical numbers documented prior to 1970. A species is considered "present" if there is at least one record of its presence in any 8-digit HUC within the 6-digit HUC.

Data source: *NatureServe, 2006*

fish species that were present before 1970 (Exhibit 6-10). Watersheds covering nearly a quarter (24 percent) of the area, however, have lost 10 percent or more of their native fish species. Reductions in diversity are especially severe in the Southwest (e.g., the lower Colorado River watershed) and the Great Lakes, with eight major watersheds (representing 2 percent of total area) having lost at least half of their native fish species.

Some watersheds are naturally more species-rich than others, and for those with greater historical diversity, even a small percentage reduction may mean the loss of numerous species in absolute terms. Although the greatest diversity of fish species is found in the Southeast, the greatest reduction in numbers has occurred in portions of the Midwest and the Great Lakes, where several watersheds have lost more than 20 species (Exhibit 6-11). In contrast, southwestern HUCs have all lost 10 or fewer species, but because these watersheds historically supported fewer species, on a percentage basis their fish faunas are regarded as less intact.

Indicator Limitations

- The incomplete historical record for freshwater fish distributions and inconsistent inventory records for contemporary fish distributions are sources of uncertainty.
- Although NatureServe has attempted to compile the most complete distributional information possible for these species at the 8-digit HUC level, these data are dynamic; new records frequently are added and existing records are revised as new information is received and as taxonomic changes occur.

Data Sources

This indicator presents a summary of data available from the NatureServe Explorer database (NatureServe, 2006) (http://www.natureserve.org/getData/dataSets/watershedHucs/index.jsp). The identity and status (current vs. historical) of all native fish species recorded in each 8-digit HUC are available from this database, along with species-by-species distribution maps at the 8-digit HUC level. Analyses based on these data have previously been reported in Master et al. (1998, 2003) and Stein et al. (2000).

References

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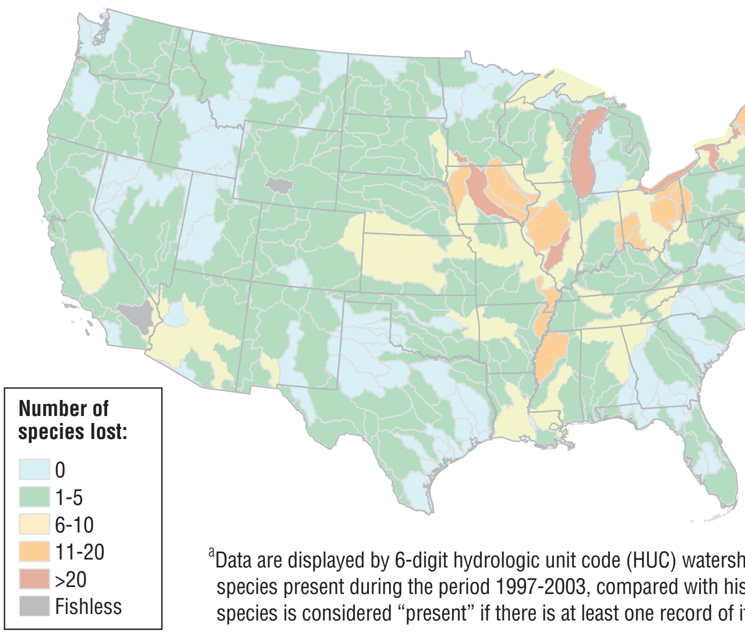
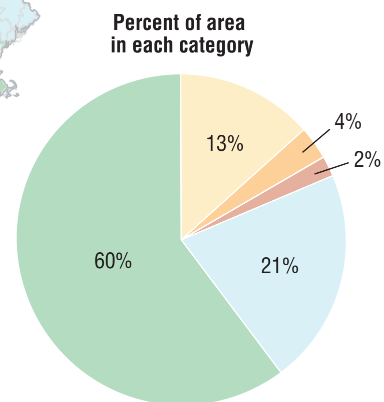
Master, L.L, S.R. Flack, and B.A. Stein. 1998. Rivers of life: Critical watersheds for protecting freshwater biodiversity. Arlington, VA: The Nature Conservancy. <http://www.natureserve.org/publications/riversOflife.jsp>

INDICATOR | Fish Faunal Intactness *(continued)*

Exhibit 6-11. Reduction in native fish species diversity in the contiguous U.S. from historical levels to 1997-2003[a]





[a]Data are displayed by 6-digit hydrologic unit code (HUC) watershed. Reduction is based on the number of native species present during the period 1997-2003, compared with historical numbers documented prior to 1970. A species is considered "present" if there is at least one record of its presence in any 8-digit HUC within the 6-digit HUC.

Data source: *NatureServe, 2006*

NatureServe. 2006. NatureServe explorer. Accessed 2006. <www.natureserve.org/explorer>

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INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest

Non-indigenous species (NIS) are one of the greatest threats to aquatic ecosystems and can impact local and regional economies (Lowe et al., 2000). The number of invasive species in estuaries of the Pacific Northwest (including Puget Sound, Columbia Estuary, and Coos Bay) is rising, and these areas can become sources of invasives to other locales. Coastal waters are particularly vulnerable to NIS transported in ballast water and introduced via aquaculture (Puget Sound Action Team, 2002). It is becoming apparent that NIS are capable of impacting estuaries along the Pacific coast, even though they are rarely addressed in routine monitoring studies. One limitation is the lack of standardized invasion metrics and threshold values.

This indicator focuses on estuarine soft-bottom communities of the Columbian Biogeographic Province located along the Pacific coast from Cape Mendocino, California, north to the Strait of Juan de Fuca at the entrance to Puget Sound, Washington. It is limited to sites with salinities of 5 parts per thousand or higher. The indicator is based on the percent abundance of NIS individuals relative to the combined abundance of native and NIS individuals in a benthic grab sample.

The data for this indicator were collected by EPA's Environmental Monitoring and Assessment Program (EMAP) using a probability survey over the 1999-2001 period (Nelson et al., 2004, 2005) and by a special probabilistic study

INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest *(continued)*

focusing on estuaries not exposed to ballast water or aquaculture. Probability sampling provides unbiased estimates of the percent abundance of natives and NIS in all estuaries in the study area, but because the data for the special study have not yet been statistically expanded, data for this indicator are based on stations sampled rather than area.

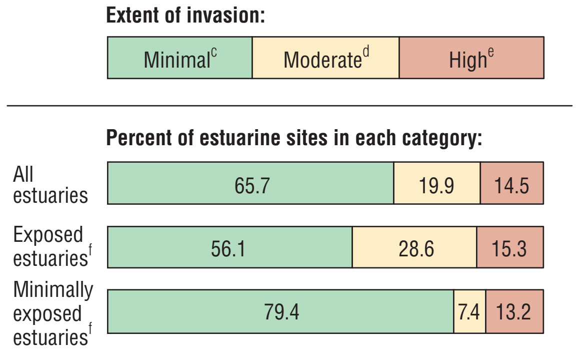
Interpretation of this indicator requires threshold values to distinguish among different levels of invasion. To determine the lowest expected level of invasion within the Columbian Biogeographic Province, EPA examined the extent of invasion in estuaries with minimal exposure to ballast water discharges and aquaculture of exotic oysters, which are the primary invasion vectors in the region. Using observed percentages of NIS at the minimally exposed estuaries as a reference, the threshold for "minimally invaded" survey sites was set at 10 percent NIS (i.e., sites were classified as minimally invaded if NIS constituted 0 to 10 percent of the individuals collected). Survey sites were classified as "highly invaded" if NIS were more abundant than native species (more than 50 percent NIS) and as "moderately invaded" if NIS constituted 10 to 50 percent of the individuals.

What the Data Show

Approximately 15 percent of the stations in the Columbian Province were highly invaded (i.e., abundance of NIS was greater than abundance of natives) and another 20 percent were moderately invaded (Exhibit 6-12). The EMAP survey showed that NIS were among the most frequently occurring anthropogenic stressors in this biogeographic region when compared to indicators of sediment contamination or eutrophication (Nelson et al., 2004).

The extent of invasion was not uniform, however, among exposed and minimally exposed estuaries. Estuaries with greater exposure to these invasion vectors were more invaded; 44 percent of the stations in the exposed estuaries were moderately to highly invaded compared to only 21 percent of the stations in minimally exposed estuaries (Exhibit 6-12). Nonetheless, the observation that 21 percent of the stations in these "pristine" estuaries were at least moderately invaded indicates that NIS can disperse widely once they are introduced into a region, so even estuaries with no direct exposure to ballast water or aquaculture are at risk of invasion.

Exhibit 6-12. Relative abundance of non-indigenous benthic species in estuaries of the Pacific Northwest, 1999-2001[a,b]



[a]**Coverage:** Soft-bottom estuaries between Cape Mendocino, CA, and the Strait of Juan de Fuca, WA (limited to sites with salinity ≥5 parts per thousand).

[b]Totals may not add to 100% due to rounding.

[c]**Minimally invaded:** 0-10% of benthic organisms belong to non-indigenous species

[d]**Moderately invaded:** >10-50% of benthic organisms belong to non-indigenous species

[e]**Highly invaded:** >50% of benthic organisms belong to non-indigenous species

[f]"Exposed" estuaries have been exposed to ballast water discharges from international shipping and/or aquaculture of exotic oysters. "Minimally exposed" estuaries have not.

Data source: *U.S. EPA, 2006*

Indicator Limitations

- This indicator presents baseline data only; trend information is not yet available.
- Studies in the San Francisco Estuary (Lee et al., 2003) and in Willapa Bay, Washington (Ferraro and Cole, in progress) have shown that the percent of NIS can vary substantially among different types of soft-bottom communities—e.g., unvegetated sediment versus sea grass beds. Thus, regional background values for the Columbian Province as a whole may not be appropriate for specific community types.
- This indicator represents percent NIS in individual benthic grabs of the soft-bottom community, but does not characterize the total number of NIS in the estuaries. It does not include benthic NIS not subject to grab sampling, particularly hard substrate organisms.
- The data for the indicator were only collected during a summer index period and thus do not capture seasonal variations.

INDICATOR | Non-Indigenous Benthic Species in the Estuaries of the Pacific Northwest *(continued)*

- The threshold values for "minimally invaded," "moderately invaded," and "highly invaded" are preliminary and require further research in order to establish their ecological significance. Specific values may differ in other biogeographic provinces.

Data Sources

Data for this indicator were collected by two different studies: EPA's National Coastal Assessment (NCA) and a special EPA study of minimally exposed estuaries. The complete results from these studies were not publicly available at the time this report went to press, but summary data from the 1999 NCA are available from Nelson et al. (2004, 2005), and the underlying sampling data can be obtained from EPA's NCA database (U.S. EPA, 2007) (http://www.epa.gov/emap/nca/html/data/index.html). Results from the special study of minimally exposed estuaries will be published in the near future. Until then, data for this indicator can be obtained from EPA's Western Ecology Division (U.S. EPA, 2006).

References

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6.3.3 Discussion

What These Indicators Say About Trends in the Diversity and Biological Balance of the Nation's Ecological Systems

Few national programs track diversity and biological balance. However, there are ROE indicators available for invertebrate communities and select vertebrates (birds and fish) and regionally for invasive species (as these can be important disruptors of ecosystem balance) and important communities of submerged aquatic vegetation (SAV). Some of these indicators show reduced or declining diversity for particular groups of animals and plants, but this is not consistent across all the ROE indicators. The particular trends of available ROE indicators are discussed below by plant and animal groupings, followed by the limitations of the available information and future challenges.

Primary Producers

Primary producers range from the microscopic plants of the oceans to the giant redwoods of California. The types of plants and the biomass they produce are fundamental to ecological systems. For example, SAV is an important biological component of aquatic systems, contributing to diversity and balance by providing habitat and food. While there is no National Indicator of trends in SAV, the SAV in Chesapeake Bay indicator (p. 3-46) provides data on trends in an important regional ecosystem. SAV has increased in the Bay over the past 25 years, but remains below its historical coverage. Contributing factors in the Bay include excessive nutrients, sediment loads, diseases, and physical disturbance.

Invertebrates

Invertebrates such as worms, insects, and crustaceans are among the most diverse group of organisms. Collectively they make up the largest component of animal biomass on the planet and are critical components of aquatic and terrestrial food webs. Trends in the composition of invertebrate communities can reflect important environmental changes.

In the nation's coastal systems, baseline measures of invertebrate biodiversity and species composition indicate that about one-fifth of estuarine area exhibits low biological condition (see the Coastal Benthic Communities indicator, p. 3-44). Because benthic invertebrates live on or in sediments, it is not surprising that many of these areas also exhibit low sediment and/or water quality. For small streams, the benthic macroinvertebrate Index of Biological Integrity exhibits a broad distribution from low to high values (see the Benthic Macroinvertebrates in Wadeable Streams indicator, p. 3-21).

Vertebrates

The biodiversity of fish, amphibians, reptiles, birds, and mammals is influenced by available food resources, the size and arrangement of suitable habitats, influxes of new species, climate and weather, and the presence of contaminants. Vertebrates often receive much attention because they are highly visible and are often near the top of the food chain.

Among vertebrates the most reliable indicator of national trends is for birds, which have been tracked since 1966 (see the Bird Populations indicator, p. 6-20). Bird populations are in dynamic flux. There appears to be a net decline of observed populations most commonly found in grasslands and shrublands, comparable increases and decreases in observed populations in woodlands, and some gains in observed populations inhabiting urban and water/wetlands areas.

Fish are distributed throughout most of the nation's aquatic and marine ecological systems. Comparisons between current and historical species compositions (see the Fish Faunal Intactness indicator, p. 6-21) indicate that one-fifth of the watersheds of the contiguous 48 states retain their full complement of fish species, while about a quarter have experienced a loss in species of 10 percent or more. Absolute losses have occurred primarily in the Midwest and the Great Lakes, while on a percentage basis, losses have been highest in the Great Lakes and the Southwest.

Invasive Species

The infiltration of new species into areas is a natural phenomenon but can be accelerated through intentional and unintentional introductions. Introduction of species such as kudzu, zebra mussels, grass carp, starlings, and nutria have had profound effects on ecological systems.[28] Many newly introduced species may lack predators or parasites that kept these species under control in their native habitats, allowing them to out-compete resident species and even dominate entire systems. While national data are lacking, the Non-Indigenous Estuarine Species in Pacific Northwest indicator (p. 6-23) shows that in the Columbian Biogeographic Province (from California to Washington), about one-third of the stations sampled were highly or moderately invaded with non-indigenous invertebrates.

Limitations, Gaps, and Challenges

A number of additional ROE indicators would help EPA better address the question of trends in diversity and biological balance. While there are ROE indicators for the extent and distribution of vegetation types, there remain gaps with respect to indicators of plant biodiversity in terrestrial and aquatic ecological systems, including both vascular and non-vascular plants. There is no ROE indicator for threatened and endangered species. Also, there are no ROE indicators for algal blooms in coastal waters, nor are there any comparable indicators for freshwater systems—e.g., the extent of nuisance aquatic plants such as the prolific growths of Eurasian milfoil and water chestnut in lakes and ponds, which continue to create water management problems.[29,30] ROE indicators of climate-related vegetation changes also are lacking (e.g., fluctuations in the extent of kelp beds along the Pacific coast related to El Niño events).[31]

There are no ROE indicators for major groups of vertebrate biota including amphibians, reptiles, and mammals. Because amphibians live both on land and in the water, their diversity and trends in their abundance could be influenced by a wide range of stressors to air, water, and land. Recent reported declines in amphibian populations worldwide indicate that losses are attributable in some areas primarily to overharvesting, in others to loss of habitat, and in still others to unknown causes,[32] but at this time there is no National Indicator that meets the criteria for this report. There also are no ROE indicators for trends in important insect and freshwater shellfish species, coastal fish and shellfish communities, microbial communities in soil and water, or genetic diversity in plant and animal populations, which could affect their viability when stressed by contaminants or habitat alteration.

Modern transportation and international trade in biota for food have caused invasive species to remain a potentially important but poorly quantified source of stress to the diversity and balance of native species. While the Non-Indigenous Estuarine Species in Pacific Northwest indicator (p. 6-23) provides some insight into the potential importance of invasive species, the full significance of accelerated species introductions is not captured by any ROE indicator.

In addition to indicator gaps and limitations, there are challenges to developing indicators of biological diversity and balance even if the data were available. For example, establishing an appropriate time scale for assessing trends in diversity and balance poses a major challenge. Biological variation is expected at annual, decadal, and even longer time scales. Because of the limited time frames over which observations have been made, parsing normal fluctuations in diversity and balance from longer-term trends is difficult. In addition, the level of interest and care of observation can change with time, confounding the determination of actual trends.

28 Lowe, S., M. Browne, S. Boudjelas, and M. De Poorter. 2000. 100 of the world's worst invasive alien species: A selection from the Global Invasive Species Database. Auckland, New Zealand: World Conservation Union, Invasive Species Specialist Group.

29 Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian water-milfoil canopies. J. Aquat. Plant Manage. 29:94-99.

30 Lake Champlain Basin Program Federal Agencies Work Group. 2005. Opportunities for federal action: Managing aquatic non-native nuisance plants and animals. <http://nh.water.usgs.gov/champlain_feds/nonnative.htm>

31 Dayton, P.K., and M. Tegner. 1984. Catastrophic storms, El Niño, and patch stability in a southern California kelp community. Science 224(4646):283-285.

32 Stuart, S.N., J.S. Chanson, N.A. Cox, B.E. Young, A.S.L. Rodrigues, D.L. Fischman, and R.W. Waller. 2004. Status and trends of amphibian declines and extinctions worldwide. Science 306(5702):1783-1786.

Appropriate spatial scales are equally important. Regional Indicators provide helpful insights into stressors affecting diversity and biological balance in some kinds of ecological systems for which there are no National Indicators. In fact, because many ecological systems vary so much by geographic region, compilations of Regional Indicators may provide the only rational approach for identifying meaningful trends. Especially important examples for biological diversity are unique ecosystems such as the Arctic and Pacific islands. Trends in physical characteristics and processes can have far-reaching effects. For example, polar bears represent important keystone species in the nation's Arctic regions, where they are stressed by warming of coastal waters that limit the duration of ice formation. Pacific island biota are stressed by invasive species and a number of other stressors.

6.4 What Are the Trends in the Ecological Processes That Sustain the Nation's Ecological Systems?

6.4.1 Introduction

Ecological systems are sustained by a number of biological, physical, and chemical processes. Collectively, these processes produce organic matter using energy (photosynthesis and chemosynthesis), transfer carbon and nutrients (through food webs and through decomposition), drive soil formation, and enable the reproduction of organisms (e.g., through pollination of plants by insects). Ecological processes also play an important role in providing ecological services such as the provision of natural resources and regulation of air and water quality.[33]

Ecological processes influence the extent, distribution, and biodiversity of systems. If primary production declines, energy flow to higher trophic levels is diminished, potentially compromising the sustainability of animal populations dependent on plants for food. Primary production is influenced by the availability of nutrients. Decreases and increases in nutrients can affect the amounts of primary production as well as the types of plants that grow, with subsequent effects on animals. The successful reproduction of plants and animals depends on the physical and chemical regimes of their environment.

Too much primary production can also cause problems, such as those that occur in eutrophic lakes that experience an overload of nutrient inputs. Eutrophic conditions can alter the composition of animal and plant life and result in reduced oxygen levels due to decomposition of organic matter. For these reasons, management of nutrient inputs is commonly driven by the potential for excessive plant growth.

Primary production and associated carbon cycling (which form the base of food webs), nitrogen cycling (e.g., ammonification and nitrification), nutrient cycling (e.g., phosphorous and other essential elements for sustainability of carbon-based life), and hydrogen/oxygen cycles (implicating hypoxic/anoxic conditions) are fundamental ecological processes within systems. Processes related to the production, transfer, and loss of biomass and the reproduction and death rates of individuals within populations are reflected in various "end states" in time, snapshots of the outcomes of integrated processes. The standing stock of a population or the amounts and types of carbon stored within an ecological system are measures of these end states. While not processes themselves, trends in end states provide some insight into the relative balance among processes. Carbon storage in forests, discussed in this section, is an example of such an end state.

EPA has long been concerned with the impacts of human activities that can affect the rates, types, and timing of ecological processes. In particular, activities that upset the balance between primary production and respiration (e.g., biochemical oxygen demand, nutrients from fertilizers and human waste, and the effects of ultraviolet radiation) and activities that affect sediment erosion and transport are important factors in water quality management. Many pesticides, chemicals used in industry, pollutants, and waste products have the potential to interfere with species reproduction (one of the most important of ecological processes). At local and regional scales, changes in land use that alter the extent and distribution of ecological systems (Section 6.2) directly affect ecological processes within and adjacent to particular areas. Concomitant changes often occur in primary production, nutrient cycling, and erosion and sediment transport. For example, shifts from forested to urban or agricultural lands influence the amounts and types of primary producers, the infiltration of water into soils, and the storage and cycling of carbon and nutrients.

Table 6-4. ROE Indicators of Trends in the Ecological Processes That Sustain the Nation's Ecological Systems

National Indicators	Section	Page
Carbon Storage in Forests	6.4.2	6-28

[33] Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Current state and trends. Washington, DC: Island Press.

6.4.2 ROE Indicators

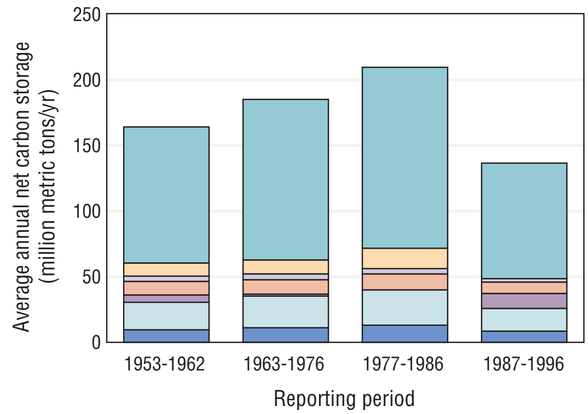
This section uses one National Indicator (Table 6-4) to examine trends in the ecological processes that sustain ecological systems. Information for this indicator comes from satellite remote sensing, geographic information systems, and independent field studies conducted as part of the USDA Forest Service Forest Inventory and Analysis. It is important to note that the data presented for carbon storage in forests include only forests classified as "timberland," which excludes about one-third of U.S. forest land cover. Timberland is defined as forests capable of producing at least 20 cubic feet per acre per year and not withdrawn from timber utilization by regulation or statute. This is an important distinction between previously illustrated trends in forest extent and type and the following discussion of carbon storage.

INDICATOR | Carbon Storage in Forests

After carbon dioxide is converted into organic matter by photosynthesis, carbon is stored in forests for a period of time in a variety of forms before it is ultimately returned to the atmosphere through the respiration and decomposition of plants and animals, or harvested from forests for use in paper and wood products. A substantial pool of carbon is stored in woody biomass (roots, trunks, and branches). Another portion eventually ends up as organic matter in forest floor litter and the upper soil horizons. Carbon storage in forest biomass and forest soils is an essential physical and chemical attribute of stable forest ecosystems, and a key link in the global carbon cycle.

This indicator, developed by the U.S. Department of Agriculture (USDA) Forest Service, tracks decadal changes in net carbon storage rates in the pools of living and dead biomass in forests in the contiguous 48 states. The carbon pools for this indicator are estimated using USDA Forest Service Forest Inventory and Analysis (FIA) data from five historical periods (circa 1953, 1963, 1977, 1987, and 1997). These data cover forest classified as "timberland" under FIA data collection procedures—that is, forests capable of producing at least 20 cubic feet per acre per year of industrial wood and not withdrawn from timber utilization by statute or regulation. Timberland makes up roughly two-thirds of U.S. forest land. Alaska and Hawaii are not included because of limited historical data. The FIA program estimates carbon storage using on-the-ground measurements of tree trunk size from many forest sites; statistical models that show the relationship between trunk size and the weight of branches, leaves, coarse roots (greater than 0.1 inch in diameter), and forest floor litter; and estimates of forest land area obtained from aerial photographs and satellite imagery. Values are converted into carbon storage based on coefficients derived from previous field studies (Smith and Heath, 2002; Smith et al., 2003; Birdsey, 1996). Forest floor litter is composed of dead organic matter above the mineral soil horizons, including litter, humus, and fine woody debris. Larger branches and logs on the ground are counted as "down dead wood." Organic carbon in soil is not included.

Exhibit 6-13. Average annual net carbon storage in forests of the contiguous U.S., by forest component, 1953-1996[a]



[a]**Coverage:** Forest land classified as "timberland," which accounts for approximately two-thirds of the forest land of the contiguous 48 states. These data do not include carbon stored in forest soil.

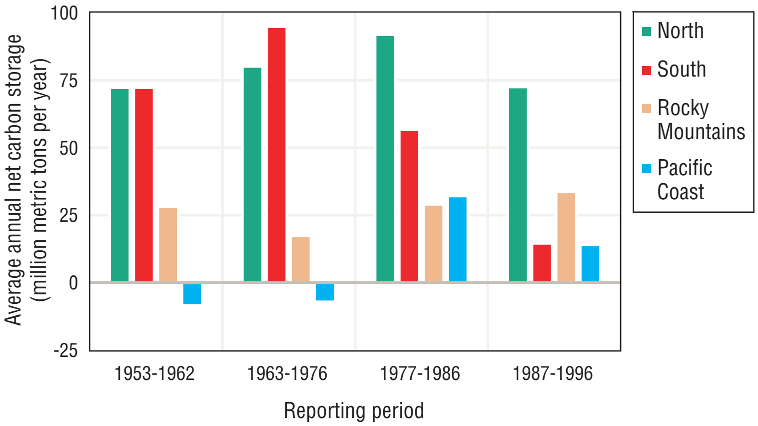
Data source: *USDA Forest Service, 2004a,b*

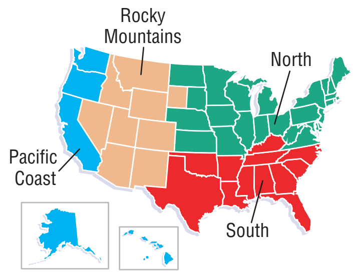
- Aboveground live trees
- Aboveground standing dead trees
- Understory vegetation
- Down dead wood (including stumps)
- Forest floor litter
- Belowground live trees (roots)
- Belowground dead wood

What the Data Show

The change in carbon inventories from year to year—i.e., net storage—reflects increases in growth as well as decreases due to harvesting, land use change, and disturbances such as fire, insects, and disease. Overall, net carbon storage in forests of the contiguous 48 states has been positive since 1953 (Exhibit 6-13), indicating that over at least the last half-century, forests have served as a sink rather than a source of carbon. The average rate of net carbon storage in forests increased between the 1950s and the 1980s, peaking at 210 million metric tons of carbon per year (MtC/yr) from 1977 to 1986. The rate declined to 135 MtC/yr for the last period of record (1987-1996), with declining storage evident in live, dead, and understory pools. This decline is thought

Exhibit 6-14. Average annual net carbon storage in forests of the contiguous U.S. by region, 1953-1996[a]





[a]**Coverage:** Forest land classified as "timberland," which accounts for approximately two-thirds of the forest land of the contiguous 48 states. These data do not include carbon stored in forest soil.

Data source: *USDA Forest Service, 2004a,b*

to be due to a combination of increased harvests relative to growth, more accurate data, and better accounting of emissions from dead wood (USDA Forest Service, 2004b). The rate of storage over this period is equivalent to approximately 9 to 10 percent of U.S. carbon dioxide emissions over a comparable period (U.S. EPA, 2005).

Carbon storage trends vary among regions of the country, depending on land use patterns and factors such as climate and soil quality. In three of the four major regions, net storage was positive throughout the period of record, with the North generally showing the largest net storage rates (Exhibit 6-14). The exception was the Pacific Coast region, which experienced net losses of forest carbon during two of the four reporting periods. Rates of net carbon storage appear to have decreased over time in the South; this trend is thought to be due to an increase in harvesting relative to growth (USDA Forest Service, 2004b). Some of the harvested carbon is sequestered in wood products.

Indicator Limitations

- The data include only forest classified as "timberland," which excludes about one-third of U.S. forest land cover. Historical data from Alaska and Hawaii are insufficient for inclusion in this indicator.
- Data are derived from state inventories that do not correspond exactly to the years identified in Exhibits 6-13 and 6-14.
- Carbon stored in forest soil is not included.
- Carbon pools are not measured, but are estimated based on inventory-to-carbon coefficients developed with information from ecological studies. These coefficients may change over time as new ecological studies are conducted, which could change storage rate estimates.

These limitations are discussed in detail in Heath and Smith (2000) and Smith and Heath (2000, 2001).

Data Sources

Exhibits 6-13 and 6-14 were previously published in the data supplement to USDA Forest Service (2004b). The numbers depicted in these figures have not been published, but were provided by the USDA Forest Service (2004a). The physical measurements used as inputs in the carbon storage models can be obtained from the FIA database (USDA Forest Service, 2005) (http://fia.fs.fed.us/tools-data/).

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USDA Forest Service. 2004a. Data provided to ERG (an EPA contractor) by Linda Heath, USDA Forest Service. December 23, 2004.

USDA Forest Service. 2004b. National report on sustainable forests—2003. <http://www.fs.fed.us/research/sustain/> (main site); <http://www.fs.fed.us/research/sustain/one_pagers/indicator%2027.pdf> (data supplement: summary); <http://www.fs.fed.us/research/sustain/documents/Indicator%2027/c5i27.pdf> (data supplement: graphics and metadata)

U.S. EPA (United States Environmental Protection Agency). 2005. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2003. EPA/430/R-05/003.

6.4.3 Discussion

What This Indicator Says About Trends in the Ecological Processes That Sustain the Nation's Ecological Systems

The ROE indicator provides data on trends in primary production and carbon cycles for terrestrial systems.[34] Primary producers capture, store, and supply solar-derived energy to other species in the system. In the forest, the energy currency is organic matter. Primary producers convert carbon dioxide into organic matter, which is then available to species throughout the ecological system as an energy resource and ultimately returns to the atmosphere (see the Carbon Storage in Forests indicator, p. 6-28). For forests, the stability of the system may depend on the balance between carbon stored in standing stock and carbon lost from the system due to harvesting. Net carbon storage has been positive for the last half-century, reflecting an overall gain in forest biomass. The rate of net storage increased between the 1950s and the 1980s, then declined through the mid-1990s. During the 1987-1996 time period, the greatest carbon storage occurred in the North and Rocky Mountain regions where there is more tree growth relative to harvesting, while the greatest decline in storage rates occurred in the South where harvesting has been increasing relative to growth. The distribution of carbon has received much attention, not only from a biological point of view but also with respect to global cycles of carbon. Increases and decreases in carbon storage suggest that other pools of carbon (e.g., within the aquatic and atmospheric environments) are also changing. The distribution of carbon among all these pools reflects a combination of processes and can also influence other chemical, physical, and biological processes.

[34] Whitmarsh, J., and Govindjee. 1999. The photosynthetic process. In: Singhal, G.S., G. Renger, S.K. Sopory, K.D. Irrgang, and Govindjee, eds. Concepts in photobiology: Photosynthesis and photomorphogenesis. New Delhi, India: Narosa Publishers; Dordrecht, The Netherlands: Kluwer Academic Publishers. pp. 11-51.

Limitations, Gaps, and Challenges

Carbon storage trends are important for assessing the future viability of ecological systems, and they have increasing utility in evaluating global carbon cycles and potential climate change. At this time, however, ROE indicators are not available for carbon storage in systems other than forests (e.g., grasslands), and the indicator presented here is restricted to timberland (versus all forest) and does not include carbon storage in soil. Direct measurement can pose a challenge; in this case, statistical models must be employed to estimate carbon storage relationships among different components of the forest ecosystem.

A further limitation of the indicator presented here is that it provides very little insight into other ecological processes across the nation. Indicators are lacking for primary production, nutrient cycling (e.g., nitrogen fixation and denitrification), secondary production, and reproduction and growth rates of populations. Indicators also are lacking for processes such as pollination, decomposition, and removal of contaminants from air and water. EPA recognizes this as a gap in understanding trends in ecological processes. To some degree, information presented in Sections 6.2 and 6.3 gives insight into the net result of ecological processes. Trends in the extent and distribution of ecological systems and in the biodiversity and balance of those systems reflect underlying processes that produce food, cycle nutrients, and sustain populations of plants and animals. Sections 6.2 and 6.3 can be thought of as addressing "end states" that indicate the results of underlying ecological processes. Trends in these end states may or may not pick up important trends in the underlying processes because systems are dynamic and internal relationships are rarely linear. Indicators of ecosystem stability or resilience are potentially important gaps in this regard.

6.5 What Are the Trends in the Critical Physical and Chemical Attributes of the Nation's Ecological Systems?

6.5.1 Introduction

Physical and chemical attributes influence and sustain ecological systems. Critical physical attributes include temperature, light, and hydrology (rainfall, soil moisture, flow rates, and sea level), as well as infrequent physical events that reshape ecological systems, such as fires, floods, and storms. Examples of critical chemical attributes include oxygen, nutrients, pH, salinity, and the presence of other chemicals in the environment.[35] Together, these attributes have driven the evolutionary history of species, and they continue to drive ecological processes, shape the conditions in which species live, and govern the very nature of ecological systems.

Species have evolved within particular physical and chemical environments. These are characterized by mean (i.e., long-term average) conditions as well as by fluctuations on time scales of a day (e.g., tidal and light/dark cycles), seasons (e.g., temperature and hydrological cycles), years (e.g., periodic climatic and fire events), and longer time scales. The occurrence of ice ages every 40,000 to 100,000 years reflects one of the longer time scales. Because critical physical and chemical attributes influence so many aspects of ecological systems, small changes in average conditions or changes in temporal variations can potentially have large effects on the extent and distribution of ecological systems and on the biodiversity of these systems.

Average conditions and the degree and periodicity of fluctuations in physical and chemical attributes vary over the surface of the globe, and species have evolved with specific niche requirements that reflect the physical and chemical states of the ecological systems in which they live. For this reason, a species that has evolved in tropical waters would have temperature requirements that are higher and narrower (the species is less able to tolerate fluctuations) than a species that has evolved in temperate waters where temperatures are lower and more variable. Reproduction and other activity patterns of species are often related to physical and chemical cues such as temperature, light, and salinity. Because species have evolved coincident with the presence (or absence) of physical disturbances, reproductive strategies may be linked with the occurrence of events that otherwise appear destructive. Thus, disturbances such as periodic fires or flooding may be essential for sustaining certain species and ecological systems where these disturbances have been present over evolutionary time scales.

Critical physical attributes reflect, in part, the influence of solar radiation. Solar radiation warms land and water masses and drives hydrologic cycles. The amount of light reaching the surface of the Earth and penetrating into its waters determines levels of photosynthesis, which is essential to the support of biological systems. Other examples of physical, chemical, and biological processes that are influenced by the amount and periodicity of light include temperature and weather conditions, photoactivation of chemicals, mutations, and the timing of reproductive cycles. Solar radiation can also have potentially harmful effects on some species. Light regimes can be influenced by changes in solar energy reaching the earth, changes in the transparency of water, and changes in sea level, which in turn can change the degree of light penetration reaching the sea floor, coral reefs, and kelp forests. The implication of climate change for changes in many aspects of ecological condition has received broad attention.[36,37]

EPA has been actively involved over its three decades in assessing and managing factors that alter the critical chemical and physical characteristics of ecological systems (e.g., temperature, pH, electrochemical [redox] potential, and the transparency of air and water). For example, the use of water for cooling purposes can result in temperature increases in receiving waters of a river, acid rain can lower the pH levels of lakes in sensitive regions, and wastewater and fertilizer can lead to low redox potentials, which affect biological communities and the cycling of both toxic and non-toxic materials. Although EPA is not directly involved in the control of hydrology—an important physical factor in the environment—hydrology greatly influences the fate and transport of pollutants in aquatic ecosystems. Changes in such factors as the amount of runoff or snowpack can affect ground water levels as well as flows into streams and rivers. Flood control efforts can alter flooding and sedimentation processes that sustain particular types of systems. Because ground water is a primary source to surface water bodies in many parts of the nation, changes in the quantity (water level) and quality of ground water influence ecological conditions not only in the hyporheic zone (below and adjacent to the stream bed) but also in surface waters. The potential impacts of climate change (whether natural or human-induced) have important consequences for virtually every aspect of ecological structure and function.

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35 Information on nutrients and potentially toxic chemicals is presented in Chapters 2, 3, and 4 of the ROE.

36 Millennium Ecosystem Assessment Board. 2005. Living beyond our means: Natural assets and human well being. <http://www.maweb.org/documents/document.429.aspx.pdf>

37 Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>

Table 6-5. ROE Indicators of Trends in the Critical Physical and Chemical Attributes of the Nation's Ecological Systems

National Indicators	Section	Page
U.S. and Global Mean Temperature and Precipitation	6.5.2	6-32
Sea Surface Temperature	6.5.2	6-37
Streambed Stability in Wadeable Streams	3.2.2	3-11
High and Low Stream Flows	3.2.2	3-8
Sea Level	6.5.2	6-39
Nitrogen and Phosphorus Loads in Large Rivers	3.2.2	3-17
Nitrogen and Phosphorus in Wadeable Streams	3.2.2	3-13
Nitrogen and Phosphorus in Streams in Agricultural Watersheds	3.2.2	3-15
Lake and Stream Acidity	2.2.2	2-42
Regional Indicators	**Section**	**Page**
Hypoxia in the Gulf of Mexico and Long Island Sound	3.5.2	3-48

6.5.2 ROE Indicators

The evaluation of trends in the critical physical and chemical attributes of the nation's ecological systems relies primarily on nine National Indicators and one Regional Indicator (Table 6-5). Information comes from a variety of sources, including satellite remote sensing, geographic information systems, monitoring programs, visual surveys, and independent field studies. Indicator data in this section are drawn from a variety of programs such as EPA's Wadeable Streams Assessment (WSA), National Aeronautics and Space Administration (NASA) remote sensing, the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center and tidal gauge network, and the U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program and stream gauge network.

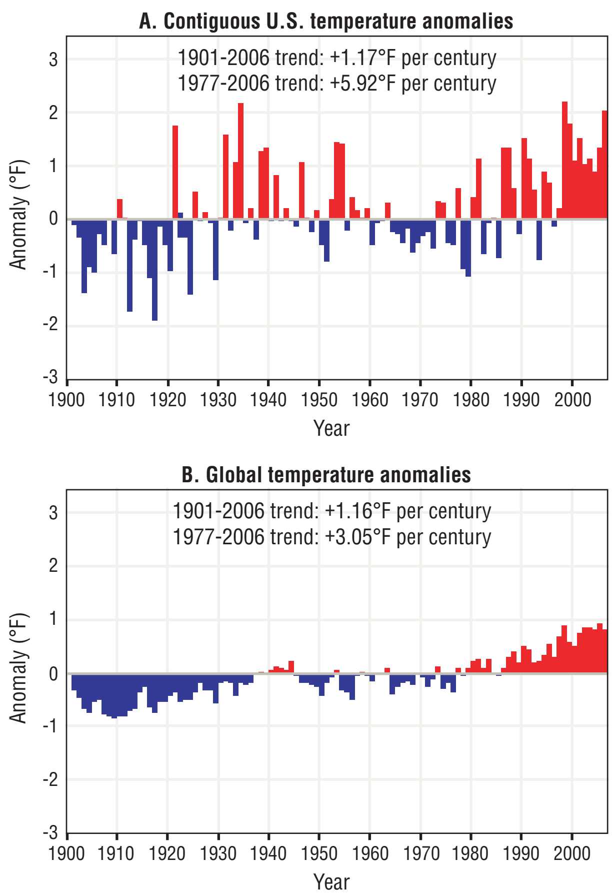
INDICATOR | U.S. and Global Mean Temperature and Precipitation

Air temperature and precipitation are two important properties of climate and are the most widely measured variables. Changes in these indicators may have wide-ranging direct or indirect effects on ecological condition and human health. These impacts may be positive or negative, depending on the effect, the magnitude of change, and the location. For example, changes in temperature can affect heat- and cold-related mortality and illness due to altered frequency and magnitude of heat waves and cold spells. Changes in temperature may also change the range and distribution of animal and plant species. Precipitation changes affect water availability and quality, which can have important effects on agricultural, forest, animal, and fisheries productivity, as well as human nutrition. Indirect effects of temperature and precipitation changes include changes in the potential transmission of vector-borne infectious diseases. These may result from alterations in the ranges and seasons of animals that carry disease or from accelerated maturation of certain infectious parasites.

This indicator shows trends in temperature and precipitation based on instrumental records from 1901 to 2006 (except for Alaska and Hawaii, where records begin in 1918 and 1905, respectively). Air temperature and precipitation trends are summarized for the contiguous U.S., as well as for 11 climate regions of the U.S., including Alaska and Hawaii (these climate regions are different from the ten EPA Regions). For context, this indicator also shows trends in global temperature (over land and sea) and global precipitation (over land) from 1901 to 2006.

Temperature and precipitation data are presented as trends in anomalies. An anomaly represents the difference between an observed value and the corresponding value from a baseline period. This indicator uses a 30-year baseline period of 1961 to 1990. To generate the temperature time series, measurements were converted into monthly anomalies, in degrees Fahrenheit. The monthly anomalies then were averaged to get an annual temperature anomaly for each year. Precipitation trends were calculated in similar fashion, starting with anomalies for total monthly precipitation, in millimeters. Monthly anomalies were added to get an annual anomaly for each year, which was then converted to a percent anomaly—i.e., the percent

Exhibit 6-15. Annual temperature anomalies in the contiguous U.S. and worldwide, 1901-2006[a]



[a]Anomalies are calculated with respect to the 1961-1990 mean.

Data source: *NOAA, 2007b*

departure from the average annual precipitation during the baseline period. Trends in temperature and precipitation were calculated from the annual time series by ordinary least-squares regression. For each of the 11 climate regions, this indicator also shows a smoothed time series, which was created from the annual series using a nine-point binomial filter (4 years on each side, averaged with decreasing weights further from the center year).

What the Data Show

Since 1901, temperatures have risen across the contiguous U.S. at an average rate of 0.12˚F per decade (1.2˚F per century) (Exhibit 6-15, panel A). Over the past 30 years, average temperatures rose at an increased rate of 0.59˚F per decade, and 5 of the top 10 warmest years on record for the contiguous U.S. have occurred since 1990. The overall warming trend is not confined to just a few anomalous years, as the last eight 5-year periods (2002-2006, 2001-2005, …1995-1999) were the eight warmest 5-year periods on record (NOAA, 2007a). Warming occurred throughout the U.S., with all but three of the 11 climate regions (all but the Central, South, and Southeast) showing an increase of more than 1˚F since 1901 (Exhibit 6-16). The greatest temperature increase occurred in Alaska (3.3˚F per century).

Trends in global temperature and precipitation provide a context for interpreting trends in temperature and precipitation in the U.S. Instrumental records from land stations and ships indicate that global mean surface temperature rose by about 1.2˚F during the 20th century (Exhibit 6-15, panel B), similar to the rate of warming within the contiguous U.S. During the last three decades, however, the U.S. warmed at nearly twice the global rate.

As global mean temperatures have risen, global mean precipitation also has increased (Exhibit 6-17, panel B). This is expected because evaporation increases with increasing temperature, and there must be an increase in precipitation to balance the enhanced evaporation (IPCC, 2007). Globally, precipitation over land increased at a rate of 1.7 percent per century since 1901, but the trends vary spatially and temporally. Over the contiguous U.S., total annual precipitation increased at an average rate of 6.5 percent per century since 1901 (Exhibit 6-17, panel A), although there was considerable regional variability (Exhibit 6-18). The greatest increases came in the East North Central climate region (11.2 percent per century) and the South (10.5 percent). Hawaii was the only region to show a decrease (-7.2 percent).

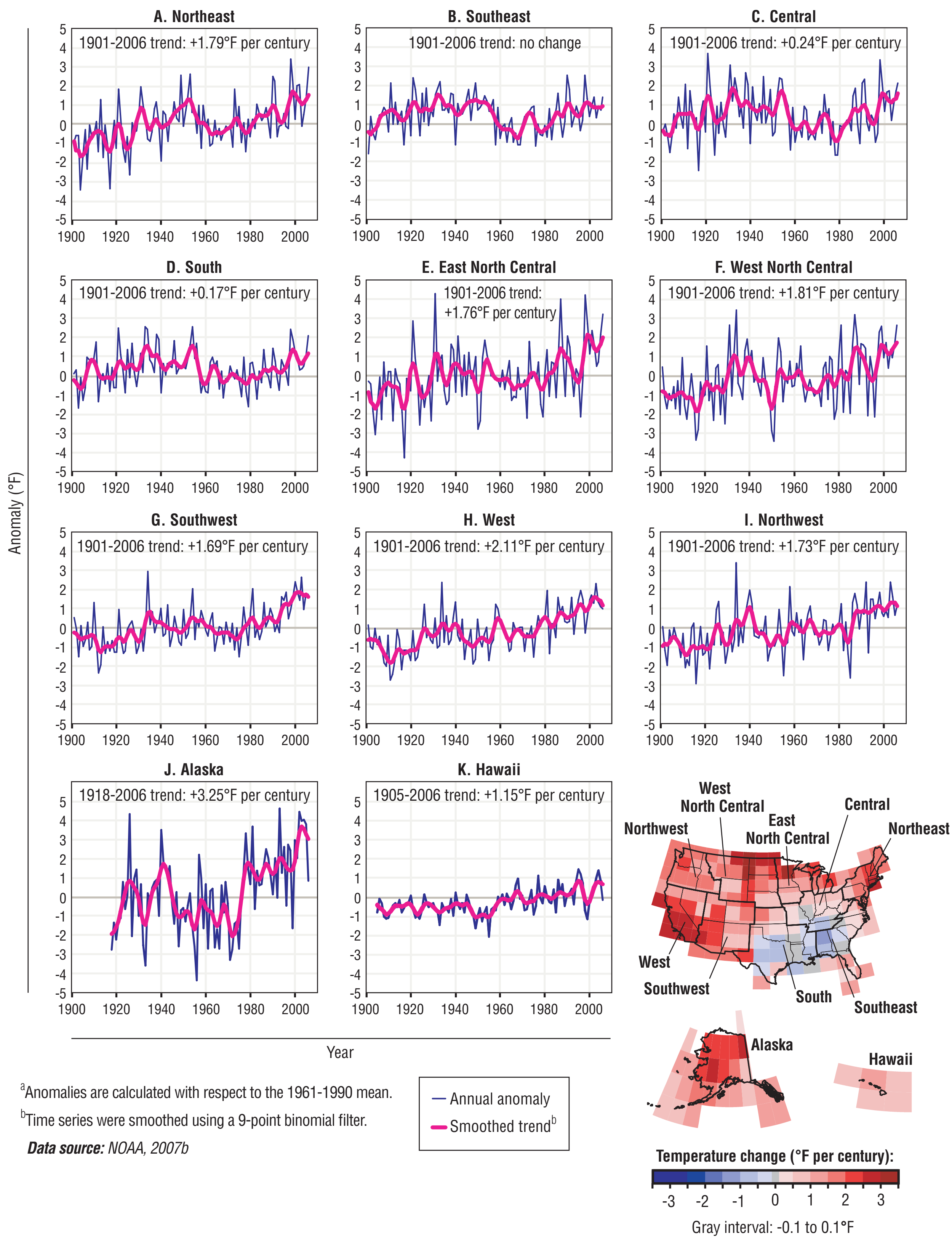
Indicator Limitations

- Biases may have occurred as a result of changes over time in instrumentation, measuring procedures (e.g., time of day), and the exposure and location of the instruments. Where possible, data have been adjusted to account for changes in these variables.
- Uncertainties in both the temperature and precipitation data increase as one goes back in time, as there are fewer stations early in the record. However, these uncertainties are not sufficient to mislead the user about fundamental trends in the data.

Data Sources

Anomaly data were provided by the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center (NCDC), which calculated global, U.S., and regional temperature and precipitation time series based on monthly values from a network of long-term monitoring stations (NOAA, 2007b). Data from individual stations were obtained from the U.S. Historical Climate Network (USHCN version 1) and the Global Historical Climate Network (GHCN), which are NCDC's online databases (NOAA, 2007c).

Exhibit 6-16. Annual temperature anomalies in the U.S. by region, 1901-2006[a]



[a]Anomalies are calculated with respect to the 1961-1990 mean.

[b]Time series were smoothed using a 9-point binomial filter.

Data source: *NOAA, 2007b*

References

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>

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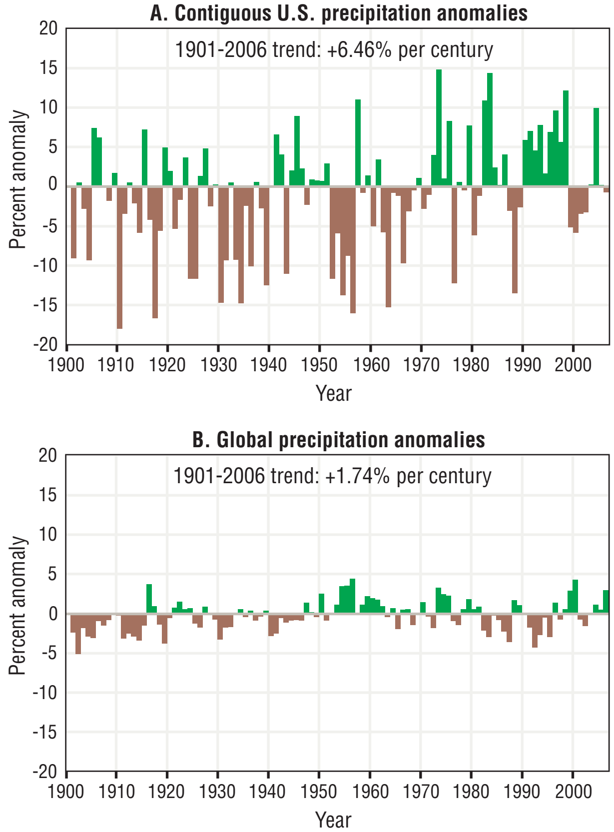
Exhibit 6-17. Annual precipitation anomalies in the contiguous U.S. and worldwide, 1901-2006[a]



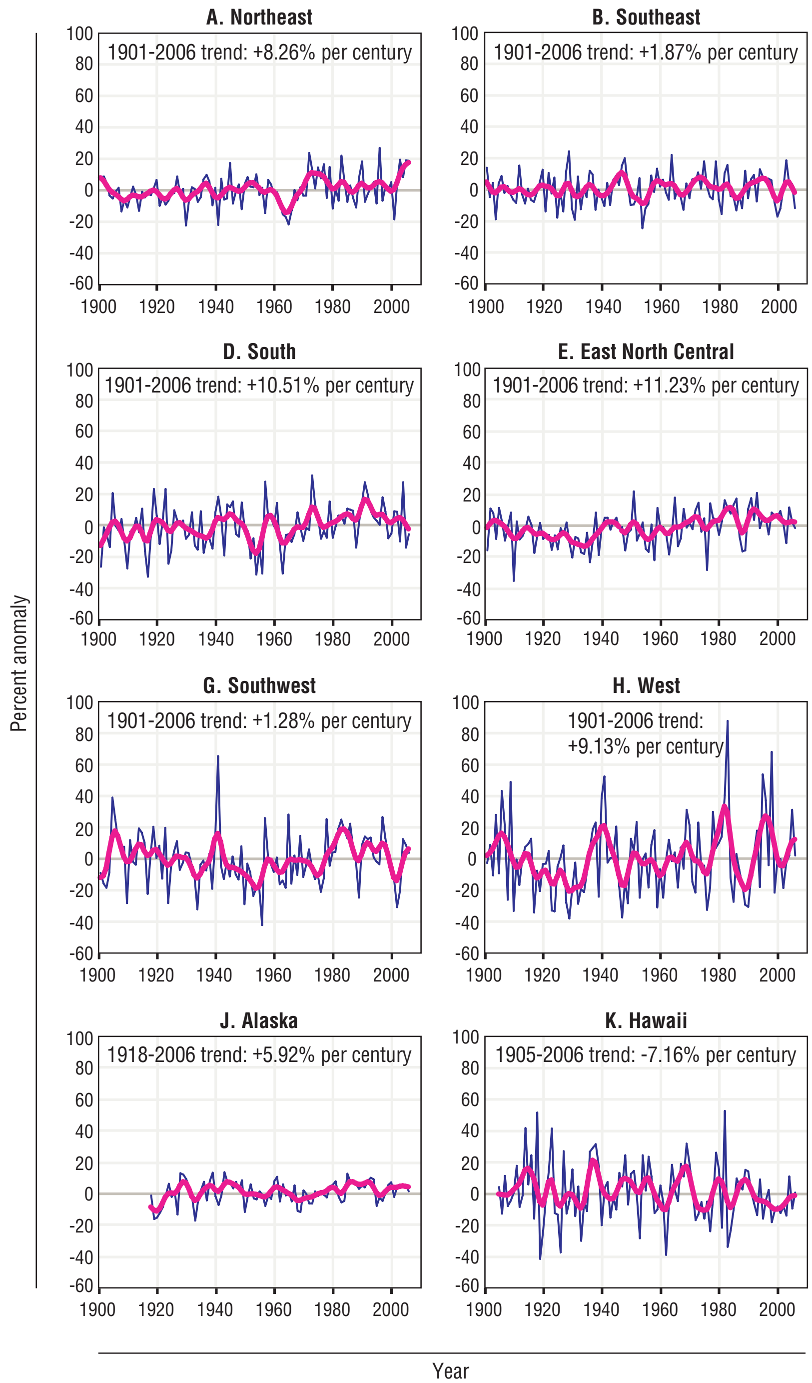
[a]Anomalies and percent change are calculated with respect to the 1961-1990 mean.

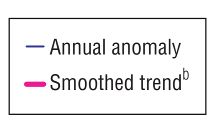
Data source: *NOAA, 2007b*

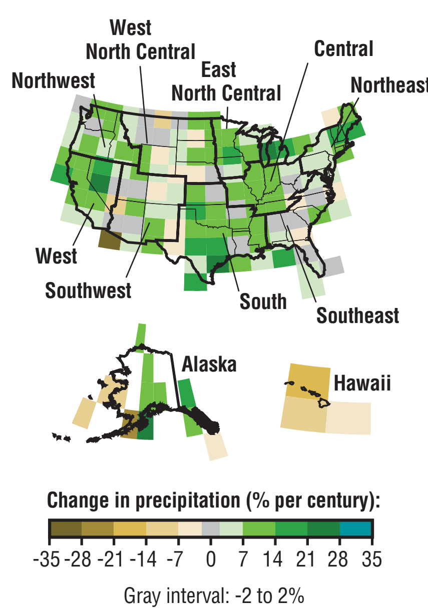
ECOLOGICAL CONDITION

ECOLOGICAL CONDITION

Exhibit 6-18. Annual precipitation anomalies in the U.S. by region, 1901-2006[a]







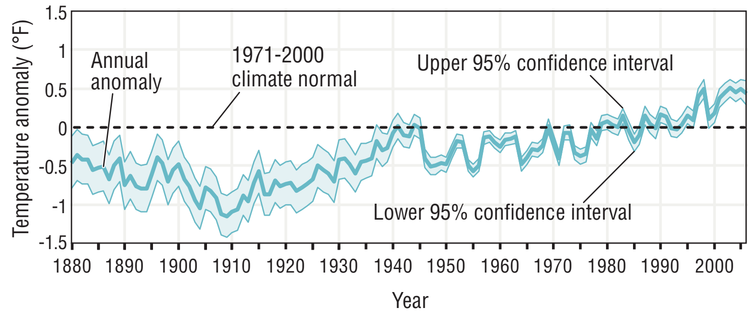
[a]Anomalies and percent change are calculated with respect to the 1961-1990 mean.

[b]Time series were smoothed using a 9-point binomial filter.

Data source: *NOAA, 2007b*

Sea surface temperature (SST) is a critical physical attribute of the oceans and coastal ecological systems. Water temperature directly affects biological and physical process rates, water column stability, and the presence and functioning of species of plants (e.g., algae, sea grasses, marsh plants, and mangroves) and animals (e.g., microscopic animals, larger invertebrates, fish, and mammals). Increases in temperature have been associated with the timing of breeding in sea turtles (Weishampel et al., 2004), stress and bleaching of coral reefs (Brown, 1997; Woodbridge and Done, 2004), alteration of species migration patterns, changes in ecological system extent and composition (Helmuth et al., 2002), and changes in the frequency or extent of blooms of harmful algae (Ostrander et al., 2000). On longer time scales (decades to centuries), rising SST may result in decreases in the supply of nutrients to surface waters from the deep sea, which could trigger a cascade of effects leading to decreases in primary production and declines in fish production (Pratchett et al., 2004), wetland loss, reductions in coastal storm buffering, and losses of local tourism. SST is both an indicator of, and a profound influence on, the climate system. Changes in SST may result from long-term cycles in ocean circulation, climate variability, or secular trends in climate (Committee on the Bering Sea Ecosystem et al., 1996).

Exhibit 6-19. Annual global sea surface temperature anomaly, 1880-2006[a]



[a]**Coverage:** Anomaly with respect to the 1971-2000 climate normal, which is plotted as zero.

Data source: *NOAA, 2007b*

This SST indicator, developed by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) and the National Center for Atmospheric Research, describes the long-term variability and change in global mean SST for the 1880-2006 period. This reconstruction provides consistent spatial and temporal data with their associated 95 percent confidence intervals. The data are compiled from in situ measurements from the International Comprehensive Ocean-Atmosphere Data Set (ICOADS) release 2 (Slutz et al., 2002) and—in recent years—from satellite imagery. Data are available from multiple sources (e.g., ship reports, buoy monitors, oceanographic profiles) from as early as 1854 (Woodruff et al., 1998). By filtering and blending data sets that use alternative measurement methods and include redundancies in space and time, this reconstruction is able to fill spatial and temporal data gaps and correct for biases in the different measurement techniques (e.g., uninsulated buckets, intakes near warm engines, uneven spatial coverage). The extended reconstructed data are shown as anomalies, or differences, from the "normal" (i.e., average) SST from 1971 to 2000. The long-term average change obtained by this method is very similar to those of the "unanalyzed" measurements and reconstructions developed by other researchers (e.g., Rayner et al., 2003).

What the Data Show

The reconstruction of SST anomalies over all latitudes indicates that the highest SSTs during the period of record occurred over the last three decades (Exhibit 6-19). Warming has occurred through most of the twentieth century and appears to be independent of measured inter-decadal and short-term variability (Smith and Reynolds, 2005). The SST warming occurred in two parts, the first between 1910 and 1940 and the second after 1970, with a roughly stationary period between 1940 and 1970. SST appears to have cooled between 1880 and 1910, although confidence intervals are wider over the early period of record. Despite that uncertainty, warming for the entire period of the indicator and for the period from 1900 forward is statistically significant.

Indicator Limitations

- The 95 percent confidence interval is wider than other methods for long-term reconstructions; in mean SSTs, this interval tends to dampen anomalies.
- The geographic resolution is coarse for ecosystem analyses but reflects long-term and global changes as well as variability.
- The reconstruction methods used to create this indicator remove almost all random "noise" in the data. However, the anomalies are also dampened when and where data are too sparse for a reliable reconstruction. The 95 percent

confidence interval reflects this "damping" effect as well as uncertainty caused by possible biases in the observations.

- Data screening results in loss of many observations at latitudes higher than 60 degrees north or south. Although the effects of screening at high latitudes are extremely small on the global average, the main effect is to lessen anomalies and widen the confidence intervals.

Data Sources

This extended reconstruction of SST, called ERSST.v3, was recently described in Smith et al. (in press). NCDC (NOAA, 2007b) provides access to monthly and annual SST and error data from this reconstruction (http://www.ncdc.noaa.gov/oa/climate/research/sst/ersstv3.php), as well as a mapping utility that allows the user to calculate average anomalies over time and space (http://nomads.ncdc.noaa.gov/#climatencdc). The ERSST.v3 reconstruction is based on in situ measurements and satellite data, both of which are available from online databases. In situ measurements are available from NOAA (2007a) (http://icoads.noaa.gov/products.html), and satellite data from NASA (2007) (http://podaac.jpl.nasa.gov/DATA_PRODUCT/SST/index.html).

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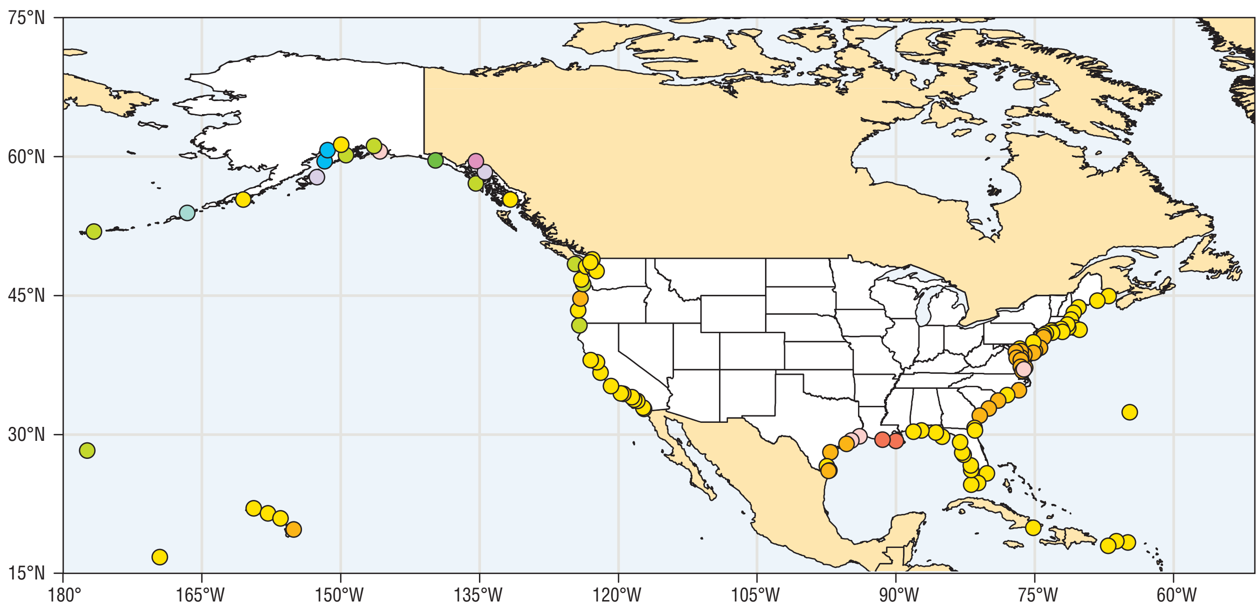
Sea level is an indicator of global and local change and a factor that affects human welfare and coastal ecosystem conditions. Coastal areas host a rich set of natural and economic resources and include some of the most developed and rapidly growing population centers in the nation. More than 100 million people globally live within 1 meter of the mean sea level and more than 40 percent of the U.S. population lives in watersheds along U.S. ocean coasts (NOAA, 2005). Changing sea levels can inundate low-lying wetlands and dry lands (Burkett et al., 2005), erode beaches (USGS, 1998), change rates of sedimentation (Olff et al., 1997), and increase the salinity of marshes, estuaries, and aquifers (Condrey et al., 1995; Williams et al., 1999). Documented consequences of sea level rise include loss of buffering against storms and floods (Burkett et al., 2005), changes in bird populations (Erwin, 2005) and land cover (Williams et al., 1999), property losses (Burkett et al., 2005), and infrastructure damage (Theiler and Hammar-Klose, 1999; U.S. Department of Transportation, 2003).

Approximately 58,000 square kilometers of land in the contiguous U.S. lie less than 1.5 meters above sea level; 80 percent of this land is in Louisiana, Florida, Texas, and North Carolina (Titus and Richman, 2001). Almost half of the shoreline studied along the U.S. Atlantic Coast was determined to be highly to very highly vulnerable to effects of sea level rise (Theiler and Hammar-Klose, 1999). The areas of highest vulnerability are high-energy coastlines where the coastal slope is low and the major landform type is a barrier island. The risks may be minimal if wetlands accretion can match or outpace sea level rises, but accretion rates vary widely (Hartig et al., 2000, Table 3).

A number of factors affect sea level, including, but not limited to, changes in sea temperature, salinity, and total water volume and mass (e.g., from melting glaciers or changes in the amount of water stored on land). Sea level rises with warming sea temperatures and falls with cooling. Changes in the total volume and mass of ocean water also result from the melting or accumulation of Antarctic and Greenland ice sheets and non-polar glaciers and changes in the amount of water stored in lakes, rivers, and ground water. As such, global average sea level change is

Exhibit 6-20. Changes in relative sea level along U.S. coasts, 1950-1999[a]



[a]Trends are based on tidal gauge measurements. Each dot represents a tidal gauge station that operated during the period 1950-1999.

Data source: *NOAA, 2006*

Mean relative sea level change (mm per year):

- -18 to -15
- -14.99 to -12
- -11.99 to -9
- -8.99 to -6
- -5.99 to -3
- -2.99 to 0
- 0.01 to 3
- 3.01 to 6
- 6.01 to 9
- 9.01 to 12

an indicator of the physical and climatic stability of the global environment.

Temporal scale is an important factor in interpreting sea level trends. Sea level changes may reflect factors such as seasonality, inter-annual to decadal scale variability such as El Niño, and/or long-term climate change (decades to centuries). Spatial scale also is important because absolute sea height does not change uniformly around the globe.

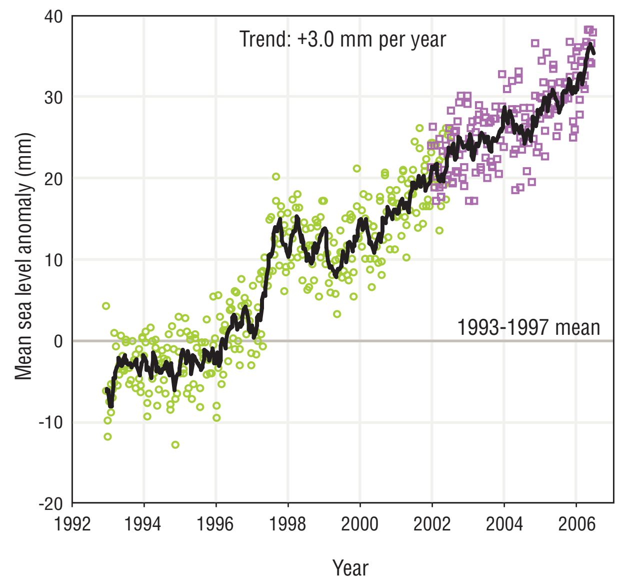
This indicator presents trends in absolute and relative sea level. Absolute sea level represents only the sea height, whereas relative sea level change is defined as sea height change plus land height changes (due to subsidence or uplift and changes in natural land accretion). Relative sea level data are from the tidal gauge measurements of the National Water Level Observation Network, composed of approximately 175 long-term, continuously operating stations located along the U.S. coast, including the Great Lakes and islands in the Atlantic and Pacific Oceans (Smith, 1980; Gill and Schultz, 2001). Tidal gauge data are presented from 1950 to 1999, although a few locations have been monitoring since the mid-1800s (NOAA, 2001). Absolute sea level data are from satellite measurements from NASA's TOPEX/Poseidon spacecraft, which uses radar to map the precise features of the ocean surface, and the "Jason" satellite, which monitors ocean circulation (Leuliette et al., 2006). The two satellites use radar altimetry to collect sea level data globally. These data have been available since 1993.

What the Data Show

Relative sea levels (combined land and sea movement) in many locations rose from 1950 to 1999, typically at rates of 0-3 millimeters per year (mm/yr) (up to 1 foot per century) (Exhibit 6-20). Relative sea level has risen more rapidly (3-6 mm/yr) along the mid-Atlantic coast from North Carolina to New Jersey and at rates as high as 9-12 mm/yr at two stations in Louisiana. Other locations, such as the southern coast of Alaska, show relative sea level drop, with a maximum decrease of 16 mm/yr. Average relative sea level rise for all U.S. coasts was not calculated because the distribution of tidal gauge stations is not spatially representative of aggregate trends, but for reference, an analysis of tidal gauge data worldwide estimated that on average, relative sea level rose between 1.5 and 2.0 mm/yr during the 20th century (Miller and Douglas, 2004).

The satellite record shows that global mean absolute sea level (i.e., independent of land movements) has increased at a rate of 3 mm (0.12 inches) per year since 1993 (Exhibit 6-21). Absolute sea levels do not change uniformly around the Earth, however. Around the U.S., areas with increasing absolute sea level include the Gulf coast and portions of the Atlantic coast (Exhibit 6-22). Areas showing a decrease include the southern part of the Pacific coast and the western Gulf of Alaska.

Exhibit 6-21. Global mean sea level, 1993-2006[a,b]



[a]Values are reported as anomalies with respect to the 1993-1997 mean.

[b]Data were collected by the TOPEX/Poseidon and Jason 1 satellite altimeters. Data were adjusted by applying an inverse barometer (air pressure) correction and removing seasonal signals.

Data source: *Leuliette et al., 2006*

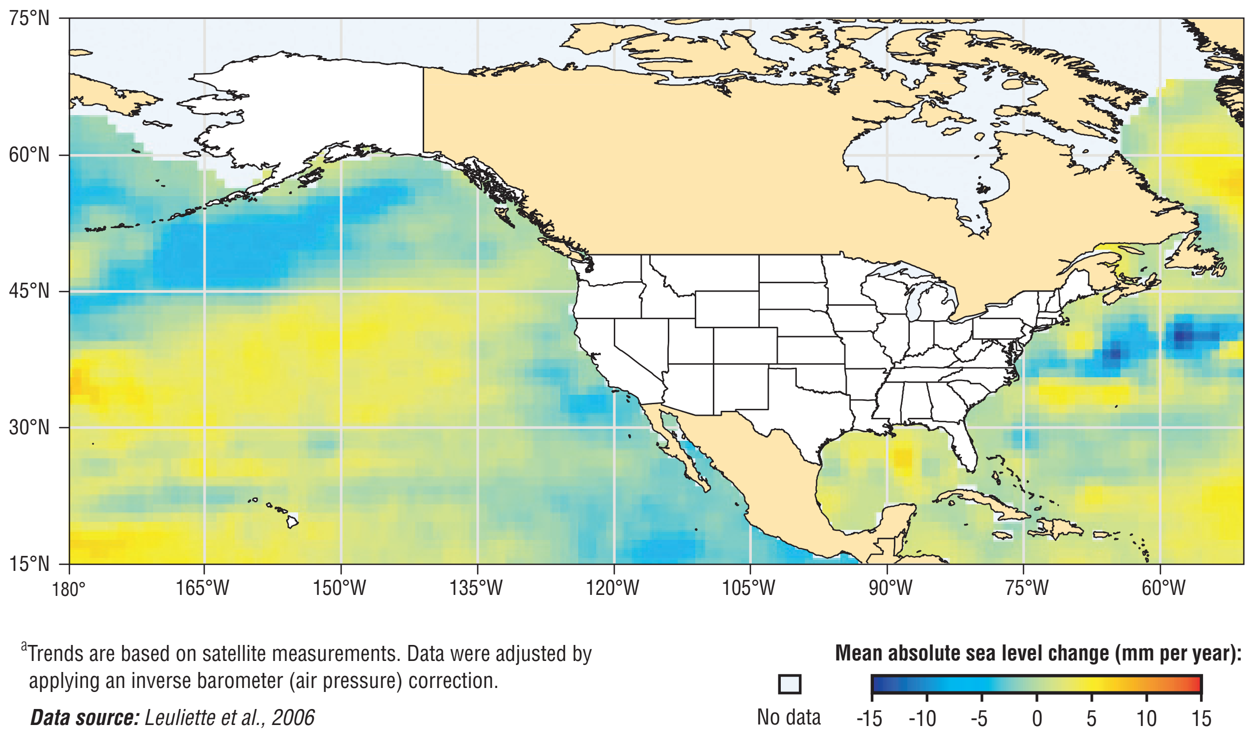
Indicator Limitations

- An estimated 50 to 60 years of data are required to obtain linear mean sea level trends having a 1 mm/yr precision with a 95 percent statistical confidence interval.
- Tidal gauge measurements do not represent more generalized (i.e., average) relative sea level change along U.S. coasts (or globally).
- Most local tidal gauge measurements cannot indicate whether changes in relative sea level are due to changes in absolute sea level or changes in land elevation.
- Satellite data are not available for a multi-decadal time series needed to separate out medium-term variability from long-term change.
- Satellite data are not horizontally precise enough to resolve sea level trends for small water bodies (such as many estuaries) or for localized interests (such as a particular harbor or beach).

Data Sources

Exhibit 6-20 is based on a map and corresponding trend data published by the National Oceanic and Atmospheric Administration's (NOAA's) National Oceans Service (NOAA, 2006) (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). These data were previously published in

Exhibit 6-22. Changes in absolute sea level along U.S. coasts, 1993-2006[a]



[a]Trends are based on satellite measurements. Data were adjusted by applying an inverse barometer (air pressure) correction.

Data source: *Leuliette et al., 2006*

NOAA (2001), along with a list of station coordinates (NOAA, 2001, Appendix I). Individual station measurements are accessible through NOAA (2006).

Exhibits 6-21 and 6-22 were produced using data provided by Leuliette et al. (2006) (time series at http://sealevel.colorado.edu/results.php; map at http://sealevel.colorado.edu/maps.php). Leuliette et al.'s analysis was based on measurements from NASA's Ocean Topography Experiment (TOPEX) and Jason satellite altimeters; results were calibrated using a model documented in Leuliette et al. (2004). Satellite measurements can be obtained from NASA's online database (NASA, 2006) (http://topex-www.jpl.nasa.gov/science/data.html).

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6.5.3 Discussion

What These Indicators Say About Trends in Critical Physical and Chemical Attributes of the Nation's Ecological Systems

Critical Physical Attributes

Information is available on trends in temperature and precipitation (see the Temperature and Precipitation indicator, p. 6-32). Across the contiguous U.S., mean temperature increased over the past century. The rate of increase in the past 30 years was higher than in the previous part of the century, amounting to more than 0.5°F per decade. Some regional trends in temperature are evident, with Alaska and the western part of the contiguous 48 states exhibiting a greater warming trend than the rest of the country. This overall warming trend is consistent with the latest findings of the Intergovernmental Panel on Climate Change (IPCC), which concluded that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."[38]

These general warming trends have occurred concurrently with rising atmospheric concentrations of greenhouse gases (see the Greenhouse Gas Concentrations indicator, p. 2-66). The IPCC confirms a connection, concluding that "Most of the observed increase in global average temperatures since the mid-20th century is *very likely* [defined by IPCC as greater than 90 percent probability] due to the observed increase in anthropogenic greenhouse gas concentrations."[39]

Temperature changes can influence the physical aspects of ecological systems, including regional and global weather and oceanographic patterns. Observed impacts associated with warming include the global retreat of mountain glaciers, reduction in snow-cover extent, earlier spring melting of ice on rivers and lakes, and increases in sea surface temperatures

[38] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg1.htm>

[39] Ibid.

and ocean heat content.[40] For example, global sea surface temperature increased throughout the past century, with the greatest increases occurring in the past three decades (see the Sea Surface Temperature indicator, p. 6-37).

The potential ecological implications of a gradual warming trend have received much attention.[41,42,43] Virtually every ecological system in the U.S. is potentially vulnerable to changes in temperature regimes that might affect physical (and in turn, biological) conditions, including coastal and marine areas,[44,45] inland freshwater and wetland systems,[46] and terrestrial systems.[47] All species have preferred ranges of temperature for survival, growth, and reproduction as well as lower and upper thermal tolerance limits. Mean temperature, seasonal changes, and other temporal fluctuations constitute species' temperature regimes. As these regimes change, several types of stresses are placed on a species. First, a species may not be well adapted to the new regime and may not be able to sustain its population. Second, other species may be better adapted and able to extend their ranges into new areas. Finally, because temperature can affect other biological and physical attributes of systems, the ecological system itself may change in a way that is not favorable for the species.

Temperature patterns are interlinked with air and water circulation patterns, which are critical to the dispersal of organisms, the movement of nutrients, and many other processes important to sustaining ecological systems. The replenishment of water over land surfaces is particularly critical, as it is a major determinant of the sustainability of the varied ecological systems that exist along a gradient of moisture from wetlands to deserts. For example, in areas where precipitation is reduced, droughts can have a pronounced and rapid influence on vegetation.[48]

Overall, precipitation increased in the U.S. over the past century (see the Temperature and Precipitation indicator, p. 6-32). Regional differences are apparent, however, with the greatest increases in the East North Central climate region and the South, very small increases in other regions, and a decrease in Hawaii. It is difficult to assign causes to such local and regional changes in precipitation because of natural climate variability (e.g., oscillations such as El Niño and others), complex interactions between aerosols (from natural and industrial processes) and clouds, and the effects of urban and rural land use on evaporation and transpiration.

Stream flows are another physical attribute that shapes and sustains ecological systems. Whether by moving sediment under high flow regimes or fostering sedimentation in lower flow regimes, stream flows impact ecological communities by forming aquatic habitats and defining habitat boundaries. Streambed stability is an important variable in this regard (see the Streambed Stability indicator, p. 3-11). Cycles of high and low flow are particularly important for species that depend on specific conditions. For example, streambeds may require an annual high flow event to restore habitat that had been filled with debris and sediment during lower flow periods. The timing of seasonal flows also coincides with the reproductive cycles of some species. Data from stream gauges indicate that over the last half-century, high flow volumes have increased substantially in many streams compared to the previous 20 years, but they have decreased in just as many (see the Stream Flows indicator, p. 3-8). Meanwhile, low flow volume appears to have increased in many streams, while variability of flow has generally decreased—indicating a smaller difference between high and low flows. Among streams in grassland and shrubland areas, the number and duration of no-flow periods also has decreased since the 1960s. While weather patterns naturally vary from year to year, trends revealing broader shifts in high and low flows and changes in no-flow periods may forewarn of instability in ecological systems.

In many locations along the U.S. coast, sea level has risen steadily, reflecting changes in water levels as well as subsidence in land in some areas (see the Sea Level indicator, p. 6-39). These changes can alter the ecological conditions in coastal areas, especially where land elevations are low. The rise of sea levels results in increased flooding that can be exacerbated during storm events. Rising sea level also can result in increased salinity levels in coastal inland waters and soils, thereby changing the chemical condition of habitats. Freshwater ecological systems are progressively lost as they are transformed into more saline inland waters or into open coastal waters.

Critical Chemical Attributes

Dissolved oxygen is critical to the support of aerobic animals and plants. In aquatic systems, dissolved oxygen levels reflect a balance between that produced by plants, consumption by all biota, and physical mixing processes. The spatial extent and timing of reduced oxygen conditions (hypoxia) and no oxygen

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[42] Millennium Ecosystem Assessment Board. 2005. Living beyond our means: Natural assets and human well being. <http://www.maweb.org/documents/document.429.aspx.pdf>

[43] Intergovernmental Panel on Climate Change. 2007. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press. <http://www.ipcc.ch/ipccreports/ar4-wg2.htm>

[44] Barry, J.P., C.H. Baxter, R.D. Sagarin, and S.E. Gilman. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. Science 267:672-675.

[45] Kennedy, V.S., R.R. Twilley, J.A. Kleypas, J.H. Cowan, Jr., and S.R. Hare. 2002. Coastal and marine ecosystems and global climate change: Potential effects on U.S. resources. Arlington, VA: Pew Center on Global Climate Change.

[46] Poff, N.L., M.M. Brinson, and J.W. Day, Jr. 2002. Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Arlington, VA: Pew Center on Global Climate Change.

[47] Malcolm, J., and L. Pitelka, 2000. Ecosystems and global climate change: A review of potential impacts on U.S. terrestrial ecosystems and biodiversity. Washington, DC: Pew Center on Global Climate Change.

[48] Allen, C., and D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. PNAS 95(25):14839-14842.

conditions (anoxia) affects the distribution and sustainability of populations of aerobic organisms. As hypoxic and anoxic areas increase in size and persistence, animals such as mollusks (snails and clams), arthropods (e.g., crabs and shrimp), and fish have proportionally less habitat within which they can thrive. For these reasons, trends in oxygen affects the sustainability of populations as well as the overall biodiversity of aquatic and marine systems.

Regional information is available on hypoxic conditions in the Gulf of Mexico and Long Island Sound (see the Hypoxia in Gulf of Mexico and Long Island Sound indicator, p. 3-48). The size of the hypoxic zones in both the Gulf of Mexico and Long Island Sound has been highly variable since the mid-1980s, with no discernable trend in either area. In both cases, there remain substantial areas in the latest year of record (2007) where low dissolved oxygen concentrations make the waters unsuitable to support most fish and shellfish species.

Nutrient levels are tightly interwoven into ecological condition. Aquatic systems are strongly influenced by nutrient levels, and nutrient inputs within a watershed may impact ecological systems far from the origin of the input (e.g., input occurs upstream, but impact occurs at the mouth of a river). Indicators focusing on the most active nutrients in aquatic systems—nitrogen and phosphorus—provide insights into trends in nutrient loads, cycles, and transport.

Nutrient loads have been examined for the Mississippi, Columbia, St. Lawrence, and Susquehanna Rivers (see the N and P Loads in Large Rivers indicator, p. 3-17). The largest of the monitored rivers, the Mississippi River, carries more than 15 times the nitrate load of the other rivers. The nutrient loads in this river more than doubled from the 1950s to the present. In contrast to the overall upward trend of nitrate loads in the Mississippi River, nitrate loads in the Columbia River nearly doubled in the 1990s compared to historical loads, but returned to historical levels by 2002. Nitrate loads increased in the St. Lawrence but did not exhibit a particular trend in the Susquehanna. Trends in phosphorus loads are variable in the Mississippi and Columbia Rivers, and show a decrease in the St. Lawrence and Susquehanna Rivers, likely due to phosphorus controls.

Baseline information on nitrogen and phosphorus concentrations is available for two sets of streams: wadeable streams and streams in agricultural watersheds. Among wadeable streams, a recent nationwide survey found that for both of these nutrients, roughly one-third of wadeable stream miles had concentrations that were substantially higher than regionally appropriate reference levels (see the N and P in Wadeable Streams indicator, p. 3-13). Agriculture-dominated watersheds are often characterized by higher loads of applied nitrogen and phosphorus fertilizers to optimize crop development. Streams located within these areas provide an indication of the extent of nutrient inputs. Baseline studies confirm that levels of nitrogen and phosphorus are elevated in many of these water bodies (see the N and P in Agricultural Streams indicator, p. 3-19).

The pH of air masses and waters is critical to biological functions, can directly affect the viability of species, and can affect the bioavailability of chemicals (both nutrients and potential toxics). There has been a decrease in wet deposition of sulfur and nitrogen compounds over the past 15 years, as discussed in Chapter 2. Associated with the decrease in deposition has been an increase in the acid neutralizing capability of water bodies (see the Lake and Stream Acidity indicator, p. 2-42). In one sensitive region, however (the Blue Ridge), fresh water bodies have yet to show recovery from acidification.

Limitations, Gaps, and Challenges

There are ROE indicators for only a few of the critical physical and chemical attributes of ecological systems. EPA would like to have ROE indicators for solar radiation over land and water as well as penetration into the nation's waters. In addition, there are no ROE indicators of disturbance regimes associated with flooding and fire. Other important gaps include water levels in lakes, the amount of snowpack or ground water available to support base flow in rivers and streams, and indicators of soil quality such as salinity or base cation saturation. Still, information is available for a few of the most critical attributes. Trends in temperature provide insight into other trends that have important biological and physical ramifications.

The indicators of trends in chemical and physical life-sustaining parameters are influenced by uncertainty. As technology changes, biases develop for data collected over long periods of time. Data collection tools may improve, creating new uncertainties when comparing recent data to historical trend data. In historical trend analyses, gaps in the record may emerge. Bridging the gaps between data series may require use of estimation or interpolation methods, or those time periods may be excluded altogether. All indicators of long-term trends are susceptible to changes in monitoring technology and historical data gaps. However, the increase in temperature and precipitation is occurring, and with the collection of additional data sets, longer-term trends can be confirmed or refuted.

Measuring trends in physical and chemical attributes is subject to a number of limitations. For the assessment of the indicator for stream flow, the U.S. Geological Survey gauging stations that generate the data for this parameter are placed on the larger tributaries and may miss trends in the smaller waterways. However, this indicator does provide valuable trend information regarding high and low flows for larger waterways. For the assessment of acidification, the focus is largely on areas where previous studies revealed an impact. This may exclude areas that are impacted to a lesser extent by acid rain.

While the large river surveys provide trend data for a watershed, it is not possible to identify the relative contributions of different land uses in the river basin. More detailed studies focus on the most common land uses contributing to nutrient runoff. Each provides useful information regarding trends in the specific system.

Information contained in the indicators represents baseline, decadal, and even century-level trends. However, for hydrologic and temperature patterns, these time periods may be too short to assess long-term changes. The field of paleoclimatology offers some promise for extending information to larger time frames.[49] In addition, the predictive capability of forecasting the extent of dissolved oxygen deficits in regional and coastal water bodies is increasing.[50] Information is also available on the distribution of solar energy over the surface of the U.S. Over time, such information could be used to evaluate trends in this physical attribute.

6.6 What Are the Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals?

6.6.1 Introduction

Chemicals can be introduced to the environment intentionally (e.g., fertilizers, pesticides, and herbicides), or unintentionally through accidental spillage or leaks of chemicals used in home and commercial applications (e.g., in wastes from municipal and industrial operations). The extent to which the presence of mixtures of chemicals influences human health and the environment has long been a focus of EPA assessments.

Biomarkers of exposure can include measures of chemical concentrations in plant and animal tissue. Such measures provide insight into the magnitude of chemical exposure that organisms receive from their environment. Measures of biological response such as biochemical concentrations (e.g., enzymes and ligands) that respond to chemical exposures can also serve as biomarkers of exposure. Examples include histopathological anomalies such as plant tissue damage from ozone or tumors in fish exposed to sediment contaminated with polycyclic aromatic hydrocarbons (PAHs). This evaluation examines the trends in biomarkers of exposures to common environmental contaminants in plants and animals as presented in the ROE indicators. It also discusses challenges in assessing trends in these biomarkers.

Chemical stressors can have a detrimental effect on plant and animal communities. Exposure of plants and animals to chemical stressors can lead to increases in tissue concentrations of the chemical stressor in the plants and animals. Once stressor concentrations are above threshold levels, they can affect physiological systems within the plants and animals and can begin to have toxic effects on individuals within the population. These individual effects can lead to changes in plant and animal community structure when chemical stressor concentrations in the environment reach levels that can affect one or more species, or when the population numbers of a key species are detrimentally affected. Biomarkers of exposure, including concentrations of chemical stressors or key biomarkers collected over time within plant and animal tissues, can help to gauge the health of plant and animal communities over time. These biomarkers of chemical exposure, when coupled with other information (e.g., toxicity testing results), can provide a basis for estimating what levels of a chemical stress can and cannot be tolerated in the environment by plant and animal communities. These biomarkers also help explain the recovery of certain animal populations (e.g., brown pelican) that were once nearly driven to extinction by specific chemical stressors. Tissue levels of pesticides, PCBs, and mercury have been used for many years to evaluate exposures to such species as the brown pelican, bald eagle, and lake trout and a host of other fish and wildlife. The Mussel Watch program relies on sampling lower-trophic-level organisms (mussels and clams) for a broad range of chemicals to evaluate exposures in coastal areas. As these examples demonstrate, measures of bioaccumulative compounds in animal tissues provide an indication of exposure levels throughout food webs.

6.6.2 ROE Indicators

Although trends in specific contaminants of concern in environmental media (e.g., sediments or air) have been available for specific locations, the indicators to evaluate trends in biomarkers of exposure to common environmental contaminants in plants and animals are mainly focused on national or regional programs that have been measuring chemical stressor concentrations in fish tissue in lakes and coastal regions of the U.S. over less than a decade. An example of such biomonitoring efforts is summarized in the National Coastal Condition Report II,[51] which was completed as a collaborative effort between EPA, the National Oceanic and Atmospheric Administration, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey.[52]

Trends in biomarkers of exposure to common environmental contaminants in plants and animals are evaluated using three National Indicators (Table 6-6). The focus of this question is on national- or regional-scale trends in biomarkers of exposure over the period in which measurements have occurred (i.e., the last one to three decades, depending upon the biomarkers of exposure). While other subregional or local-scale efforts concerning monitoring of biomarkers of exposure cannot be covered here, they are no less important.

[49] National Oceanic and Atmospheric Administration. 2003. North American drought: A paleo perspective. <http://www.ngdc.noaa.gov/paleo/drought/drght_home.html>

[50] Longstaff, B.J., D. Jasinski, and P. Tango. 2005. Ecological forecast—summer 2005. Monitoring and Analysis Subcommittee. Chesapeake Update.

[51] U.S. Environmental Protection Agency. 2002. EMAP research strategy. EPA/620/R-02/002.

[52] Within the U.S. Geological Survey, the Biomonitoring of Environmental Status and Trends (BEST) Program is another example of a national program mandated to collect biomarkers of common contaminant exposure. Although monitoring of fish contaminant concentrations is a focus of this program, this program also monitors common pollutants in many other aquatic and terrestrial receptors, such as upper trophic level receptors (fish-eating birds like the bald eagle), and catalogues biomarker data collected from many sources into an online database.

Table 6-6. ROE Indicators of Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals

National Indicators	Section	Page
Coastal Fish Tissue Contaminants (N/R)	3.8.2	3-61
Contaminants in Lake Fish Tissue	3.8.2	3-63
Ozone Injury to Forest Plants	2.2.2	2-24

N/R = National Indicator displayed at EPA Regional scale

6.6.3 Discussion

What These Indicators Say About Trends in Biomarkers of Exposure to Common Environmental Contaminants in Plants and Animals

The ROE indicators provide a baseline of recent conditions against which future trends can be assessed. Lipophilic chemicals such as polychlorinated biphenyls (PCBs), DDT, and methylmercury are present in fish tissues throughout most of the nation's freshwater lakes and coastal systems (Coastal Fish Tissue indicator, p. 3-61; Lake Fish Tissue indicator, p. 3-63), which shows widespread exposure to these bioaccumulative compounds. Some judgment concerning these levels can be made by reference to benchmarks that relate to tissue residues. For example, approximately one-fifth of estuarine fish samples were found to have at least one contaminant at levels that exceed commonly used benchmarks. Differences are apparent across EPA Regions. The contaminants most responsible for exceedances were PCBs, mercury, DDT, and PAHs.

Foliar injury from ozone pollution disrupts plant/tree physiology. Baseline data indicate that exposure of forests to ozone levels varies geographically, with more severe injury generally occurring in the eastern U.S. than in the West (Ozone Injury to Forest Plants indicator, p. 2-24). Up to 7 percent of sites had severe foliar injury in some EPA Regions, while no injury was observed at sites in Regions 8 and 10.

Limitations, Gaps, and Challenges

Few national programs involve unbiased assessment that can support indicators of trends in national conditions in biomarkers of exposure. While there are tissue-level ROE indicators for fish, there are no similar indicators for plants (either aquatic or terrestrial) or wildlife species. This represents a gap in EPA's ability to identify trends in biomarkers of exposure to common environmental contaminants in plants and animals.

Among the primary challenges relating to monitoring biomarkers of exposure are the following:

- To monitor a single biomarker of exposure on a national or regional scale requires a great deal of planning, coordination, and resources. Biomarkers are more costly and time-consuming to measure than chemical concentrations in other media (e.g., water, sediment, air), because the living things that require measurement are more difficult to collect and/or analyze for the chemical stressors.
- The biomarkers of exposure need to be clearly linked to biomarkers of effects to be useful for predicting whether the function of plant or animal communities is being affected by the concentrations of chemical in the environment. In many cases, capabilities are currently lacking to link biomarkers of exposure with biomarkers of effects. In addition, most monitoring focuses on the media within which plants and animals live (i.e., air and water), and does not address the body burden of the chemical in the plant or animal or biomarkers of effects.
- With a myriad of environmental contaminants in the environment, it is difficult to prioritize which contaminants should be monitored in biological tissues. Classically, the organochlorine pesticides (e.g., DDT), PCBs, and mercury have been monitored in fish tissues in the aquatic environment. However, in the future, new chemicals may emerge as equally or more important (see Chapter 7).