REPORT TO THE PRESIDENT

SUSTAINING ENVIRONMENTAL CAPITAL: PROTECTING SOCIETY AND THE ECONOMY

Executive Office of the President

President's Council of Advisors on Science and Technology

JULY 2011

REPORT TO THE PRESIDENT
SUSTAINING ENVIRONMENTAL CAPITAL: PROTECTING SOCIETY AND THE ECONOMY

Executive Office of the President

President's Council of Advisors on Science and Technology

JULY 2011

About the President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology (PCAST) is an advisory group of the nation's leading scientists and engineers, appointed by the President to augment the science and technology advice available to him from inside the White House and from cabinet departments and other Federal agencies. PCAST is consulted about and often makes policy recommendations concerning the full range of issues where understandings from the domains of science, technology, and innovation may bear on the policy choices before the President. PCAST is administered by the White House Office of Science and Technology Policy (OSTP).

For more information about PCAST, see www.whitehouse.gov/ostp/pcast.

The President's Council of Advisors on Science and Technology

Co-Chairs

John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy

Eric Lander
President
Broad Institute of Harvard and MIT

Vice-Chairs

William Press
Raymer Professor in Computer Science and Integrative Biology
University of Texas at Austin

Maxine Savitz
Vice President
National Academy of Engineering

Members

Rosina Bierbaum
Dean, School of Natural Resources and Environment
University of Michigan

Christine Cassel
President and CEO
American Board of Internal Medicine

Christopher Chyba
Professor, Astrophysical Sciences and International Affairs
Director, Program on Science and Global Security
Princeton University

S. James Gates, Jr.
John S. Toll Professor of Physics
Director, Center for String and Particle Theory
University of Maryland, College Park

Shirley Ann Jackson
President
Rensselaer Polytechnic Institute

Richard C. Levin
President
Yale University

Chad Mirkin
Rathmann Professor, Chemistry, Materials Science and Engineering, Chemical and Biological Engineering and Medicine
Director, International Institute for Nanotechnology
Northwestern University

Mario Molina
Professor, Chemistry and Biochemistry
University of California, San Diego
Professor, Center for Atmospheric Sciences
Scripps Institution of Oceanography
Director, Mario Molina Center for Energy
and Environment, Mexico City

Ernest J. Moniz
Cecil and Ida Green Professor of Physics
and Engineering Systems
Director, MIT's Energy Initiative
Massachusetts Institute of Technology

Craig Mundie
Chief Research and Strategy Officer
Microsoft Corporation

Ed Penhoet
Director, Alta Partners
Professor Emeritus of Biochemistry
and Public Health
University of California, Berkeley

Barbara Schaal
Mary-Dell Chilton Distinguished Professor of
Biology, Washington University, St. Louis
Vice President, National Academy of Sciences

Eric Schmidt
Executive Chairman
Google, Inc.

Daniel Schrag
Sturgis Hooper Professor of Geology
Professor, Environmental Science
and EngineeringDirector, Harvard University-
wide Center for Environment
Harvard University

David E. Shaw
Chief Scientist, D.E. Shaw Research
Senior Research Fellow, Center for
Computational Biology and Bioinformatics
Columbia University

Ahmed Zewail
Linus Pauling Professor of Chemistry
and Physics
Director, Physical Biology Center
California Institute of Technology

Staff

Deborah D. Stine
Executive Director

Mary Maxon
Deputy Executive Director

Danielle Evers
AAAS Science and Technology Policy Fellow

Gera Jochum
Policy Analyst

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

President Barack Obama
The White House
Washington, D.C. 20502

Dear Mr. President,

We are pleased to transmit to you the President's Council of Advisors on Science and Technology (PCAST) report on *Sustaining Environmental Capital: Protecting Society and the Economy*. It consists of a 4-page Executive Report prepared by the full PCAST plus the longer report of the working group (WG) that PCAST constituted on this topic. The working group was co-chaired by PCAST members Rosina Bierbaum and Barbara Schaal and included three other PCAST members (Mario Molina, Ed Penhoet, and Daniel Schrag) in addition to 11 other experts from academic, corporate, philanthropic, and non-governmental organizations.

The central messages of this report are two. First, the economic and environmental dimensions of societal well-being are **both** indispensable, as well as tightly intertwined. Second, even as the government is rightly focused on the direct threats to the economic aspects of well-being in the form of recession, unemployment, and the stagnation of the standard of living of the middle class, it must not fail to address the threats to both the environmental **and** the economic aspects of well-being that derive from the accelerating degradation of the environmental capital—the Nation's ecosystems and the biodiversity they contain—from which flow "ecosystem services" underpinning much economic activity as well as public health, safety, and environmental quality.

Our study is a sequel to the 1998 report of President Clinton's PCAST, *Teaming with Life: Investing in Science to Understand and Use America's Living Capital*. Based on the intervening 13 years of rapid advance in both environmental science and environmental economics, this new work extensively updates and expands the earlier study's assessment of the state of the Nation's biodiversity and other environmental capital, the services derived from this capital, the escalating threats in this domain, and the needed remedies. Among many increases since 1998 in our understanding of these matters, it is now much clearer than before that the historic drivers of degradation of environmental capital—replacement of complex natural ecosystems with simpler man-made ones, invasive species, overexploitation of commercially valuable plants and animals, chemical pollution—are being compounded and amplified to a rapidly growing degree by global climate change.

The largest part of the new report is focused on solutions—why government has an essential role to play in the stewardship of environmental capital, what approaches are most promising for doing so both alone and in concert with the private sector, and what specific measures this Administration could embrace to most cost-effectively improve both the government's and the private sector's performance in protecting these crucial assets. The recommended measures include ways to better integrate and utilize existing data and models across the relevant Federal agencies, as well as to fill gaps in the data and improve the models over time; increased agency use of advances in the valuation of environmental capital and ecosystem services in planning and management decisions; targeting Federal conservation investments to achieve greater benefits at the same or lower costs; and employing the increasingly sophisticated tools of eco-informatics to improve public and private decision-making about the management of environmental capital .

The essence of PCAST's findings on this issue is captured in our 4-page Executive Report and the 9-page Summary at the beginning of the Working Group's report. If your time and interest allow, we'd recommend the introductory chapter of the WG report, "Environmental Capital, Biodiversity, and Human Well-Being," as the next most important focus of your attention.

PCAST very much appreciates the opportunity to provide you with this input on a topic we believe to be of critical importance to the Nation's future, and we hope you find it useful. As always, we would be pleased indeed to have the opportunity to discuss our findings and recommendations with you in person and/or to respond in writing to questions you may have.

John P. Holdren
PCAST Co-Chair

Eric Lander
PCAST Co-Chair

The President's Council of Advisors on Science and Technology

Executive Report

Sustaining Environmental Capital: Protecting Society and the Economy

Ecosystems and the biodiversity they embody constitute "environmental capital" on which human well-being heavily depends. The "ecosystem services" that flow from this capital include formation of soil and renewal of its fertility, management of flows of fresh water, maintenance of the composition of the atmosphere, pollination of flowers and crops, control of the distribution and abundance of pests and pathogens, production of fish and game in unmanaged and lightly managed ecosystems, aesthetic and recreational values from pristine landscapes, maintenance of the "genetic library" of global biodiversity as a source of future insights and innovations benefitting humankind, and important contributions to keeping climatic conditions in the range to which human society and current ecosystems are adapted.

It has become increasingly clear, however, that biodiversity and other important components of the environmental capital producing these services are being degraded by human activities, and that the degradation of this capital has already impaired some of the associated services, with significant adverse impacts on society: damaging floods arising from deforested watersheds and heavier precipitation events; increasing costs of fresh water supply; dramatic expansion of annual areas burned and property destroyed in wildfires; increases in the frequency and destructiveness of forest-pest outbreaks; increased destruction from powerful storms; and the peaking and decline of the global ocean fish catch despite increased fishing effort.

The root causes of the degradation of environmental capital are the combined pressures of population growth, rising affluence, and frequent reliance on environmentally disruptive technologies to meet the associated material demands. All of these factors are compounded by bad management, traceable in part to under-appreciation of the importance of environmental capital for human well-being and to the exclusion of the value of its services from the economic balance sheets of producers and consumers. The proximate causes of the degradation include: widespread conversion of natural ecosystems to high-intensity human uses; exploitation, beyond sustainable yield, of commercially valuable wild plants and animals; introduction of invasive organisms that crowd out or otherwise kill off indigenous ones; emissions and spillovers of ecologically harmful substances from industry and agriculture; and, most recently, the growing impacts of global climate change resulting from heat-trapping gases and particles added to the atmosphere by human activities.

These are challenges that cannot be met without a strong helping hand from government. The main reason is the set of perverse incentives for private decision-makers—firms and individuals—in relation to ecosystems and ecosystem services when government does not intervene. In the absence of such intervention, individuals and firms are able to capture the benefits of activities that produce climate change and other forms of ecosystem disruption but are able to avoid most of the attendant damages, which are spread across society. Much of the world's environmental capital, moreover, consists of common-property resources rather than privately held assets; in part because of free-rider problems, private firms and individuals have little incentive, absent requirements imposed by government, to invest in maintaining or growing capital of this kind.

The tools available to governments for dealing with this challenge are of two kinds: measures that change the incentives of private actors in relation to their use of or impact upon environmental resources; and direct action by governments in relation to ecosystems under their control (e.g., parks, national forests, other public lands, territorial waters), including acquiring additional ones, restoring degraded ones, protecting pristine ones, and managing those subject to multiple uses so as to maximize benefit flows consistent with sustainability. The government's capacity to appropriately influence the behavior of private actors toward environmental capital, as well as to better manage the environmental capital that is directly under the government's control, can be improved **both** by better use of available understandings, models, and data on these matters **and** by focused efforts to upgrade the relevant understandings, models, and databases over time.

In the report we transmit here, PCAST's Working Group on Biodiversity Preservation and Ecosystem Sustainability addressed the needs and opportunities in relation to both of these dimensions of the capacity of governments—and especially the U.S. Federal government—to fulfill more effectively their responsibility in relation to the protection of environmental capital and ecosystem services. The Working Group's recommendations, which we endorse, involve a three-pronged effort encompassing ways to make better use of existing knowledge, to support the generation of essential new knowledge, and to expand the use of informatics. We here boil down those recommendations to the following six key points.

1. **The U.S. government should institute and fund a Quadrennial Ecosystems Services Trends (QuEST) Assessment.** QuEST should provide an integrated, comprehensive assessment of the condition of U.S. ecosystems; predictions concerning trends in ecosystem change; syntheses of research findings on how ecosystem structure and condition are linked to the ecosystem functions that contribute to societally important ecosystem services; and characterization of challenges to the sustainability of benefit flows from ecosystems, together with ways to make policy responses to these challenges more effective. The QuEST assessment should draw and build upon the wide variety of ongoing monitoring programs, previously conducted and ongoing assessments of narrower scope, and the expanded monitoring and species-discovery efforts for which we also call in this Report. And, it should be closely coordinated with the quadrennial National Climate Assessment mandated by the Global Change Research Act of 1990.

2. **The U.S. Department of State, in coordination with the Office of Science and Technology Policy (OSTP), should take a leading role in the development of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).** The goal of IPBES is regular, thematic, global assessments of biosphere change, as well as preliminary assessments of emerging issues. The U.S. contribution to IPBES should be derived from and coordinated with the U.S. QuEST Assessment described above. Long-term oversight of this effort could be assigned to the Committee on International Science, Engineering, and Technology of the National Science and Technology Council (NSTC), the Sustainability Task Force of the NSTC's Committee on Environment, Natural, Resources, and Sustainability (CENRS), or a working group created between the Department of State and CENRS.

3. **Federal agencies that implement biodiversity and ecosystem conservation programs should prioritize expenditures based on cost efficiency.** Federal agencies collectively currently spend more than $10 billion annually on ecosystem restoration activities, land and easement purchases, and incentive payments, activities aimed primarily at conserving biodiversity or protecting and restoring ecosystem services within the United States. While additional funding for these conservation investments is warranted, much more careful targeting could achieve greater environmental benefits at the same cost. The Council on Environmental Quality (CEQ) should assist in this effort by reviewing conservation programs and identifying those that should be subject to this recommendation (e.g., Title 2 Farm Bill payments, mitigation payments, etc.).

4. **Federal agencies with responsibilities relating to ecosystems and their services (e.g., EPA, NOAA, DOI, USDA) should be tasked with improving their capabilities to develop valuations for the ecosystem services affected by their decision-making and factoring the results into analyses that inform their major planning and management decisions.** This will entail expanding current efforts on ecosystem-service valuation in EPA, USDA, and other agencies, as well as generating new knowledge about the ecosystem-service impacts (in both physical and value terms) of activities taking place on both public and private lands. The Office of Management and Budget (OMB), OSTP, and CEQ should ensure that the methodologies are developed collaboratively across agencies.

5. **CENRS should identify the most important data gaps within existing biodiversity inventories and Federal and regional ecological monitoring systems, and clarify priorities and agency roles and funding for filling these.** Further, OSTP and CEQ, with the help of NSTC, should encourage and coordinate cross-scale and cross-agency collaboration in monitoring. There are a number of key areas in which such collaboration in monitoring could rapidly improve the information base available for ecosystem assessment and management. Among other dimensions of such collaboration, recommendations should be developed for integrating the existing monitoring networks with the help of state-of-the art informatics.

6. **NSTC should establish an Ecoinformatics-based Open Resources and Machine Accessibility (EcoINFORMA) initiative.** This initiative would maximize financial savings by enabling integration and utilization of current knowledge (held by many different agencies) to inform decisions while facilitating the gathering of new essential knowledge. EcoINFORMA is needed to ensure

that Federal agency data relevant to biodiversity and ecosystems, as well as the socio-economic and geophysical data required in support of ecosystem valuation and decision-support, are published in machine-readable, interoperable format to facilitate research engagement by public, private, academic, and other stakeholders, and to support policy- and decision-making at Federal, state, and local levels. In support of EcoINFORMA, OMB should enforce existing requirements that Federal agencies publish data related to biodiversity preservation and ecosystem services within one year of collection. EcoINFORMA should interact with international biodiversity and ecosystem information systems in the development of globally accepted biodiversity and ecosystem information standards, and should seek out and encourage partnerships with the private and academic sectors to develop innovative tools for data integration, analysis, visualization, and decision making.

The President's Council of Advisors on Science and Technology

Sustaining Environmental Capital: Protecting Society and the Economy

Working Group Report

PCAST Biodiversity Preservation and Ecosystem Sustainability Working Group

Co-Chairs

Rosina Bierbaum*
Dean, School of Natural Resources and Environment
University of Michigan

Barbara Schaal*
Chilton Professor of Biology
Washington University,
St. Louis Vice President
National Academy of Sciences

Members

Gretchen C. Daily
Associate Professor (Research)
Director, Tropical Research Program
Sr. Fellow, Institute for International Studies
Stanford University

Robert Guralnick
Associate Professor, Ecology and Evolutionary Biology
Curator, Museum of Natural History
University of Colorado, Boulder

Alon Halevy
Head
Structured Data Group
Google Research

Peter Kareiva
Chief Scientist
The Nature Conservancy (TNC)

Josh Knauer
President and CEO
Rhiza Labs, LLC

Anthony "Tony" Michaels
Managing Director
Proteus Environmental Technologies, LLC

Mario Molina*
Professor, Chemistry and Biochemistry
University of California, San Diego
Professor, Center for Atmospheric Sciences
Scripps Institution of Oceanography
Director, Mario Molina Center for Energy and Environment, Mexico City

Jonathan Patz
Professor and Director
Global Environmental Health
University of Wisconsin, Madison

Ed Penhoet*
Director, Alta Partners
Professor Emeritus
Biochemistry and Public Health
University of California, Berkeley

Charles Perrings
Professor
School of Life Sciences
Arizona State University

Peter H. Raven
President Emeritus
Missouri Botanical Garden

Walter Reid
Director
Conservation and Science Program
David and Lucile Packard Foundation

Daniel Schrag*
Sturgis Hooper Professor of Geology
Environmental Science and Engineering
Director, Center for Environment
Harvard University

Diana Wall
University Distinguished Professor
Director
School of Global Environmental Sustainability
Colorado State University

* PCAST member

Staff

Meredith A. Lane
Policy Analyst

Mary Maxon
Deputy Executive Director, PCAST

Table of Contents

Summary

The Character and Fate of Environmental Capital

Ecosystems and the biodiversity they embody constitute "environmental capital" on which society depends in multifaceted ways. The "ecosystem services" in support of human well-being that flow from this capital include formation of soil and renewal of its fertility, management of flows of fresh water, maintenance of the composition of the atmosphere, pollination of flowers and crops, control of the distribution and abundance of pests and pathogens, production of fish and game in unmanaged and lightly managed ecosystems, aesthetic and recreational values from pristine landscapes, maintenance of the "genetic library" of global biodiversity as a source of future insights and innovations benefitting humankind, and important contributions to keeping climatic conditions in the range to which human society and current ecosystems are adapted.

It has been increasingly well documented over the course of the last few decades, however, that biodiversity and other important components of the environmental capital producing these services are being progressively degraded by human activities. It is becoming clearer, as well, that the degradation of this capital has already reduced or rendered less reliable some of the associated services, with significant adverse impacts on society. These impacts include: damaging floods arising from deforested watersheds and heavier precipitation events; increasing costs of fresh water supply (higher pumping costs from declining water tables, increased treatment costs because of pollution and declining efficacy of natural purification); dramatic expansion of annual areas burned and property destroyed in wildfires; increases in the frequency and destructiveness of forest-pest outbreaks; disappearance or diminution of economically valuable freshwater fish populations in waters affected by acidification, other pollution, and warming; increased destruction from storms and tsunamis because buffering mangroves have been destroyed by coastal development; the pole-ward spread of tropical diseases; and the peaking and decline of the global ocean fish catch despite increased fishing effort.

The root causes of the degradation of environmental capital and the associated diminution of ecosystem services are to be found in the combined pressures of population growth, rising affluence, and frequent reliance on environmentally disruptive technologies to meet the associated material demands, with the damages frequently compounded by bad management—attributable partly, in turn, to widespread under-appreciation of the importance of environmental capital for human well-being and to the absence of the value of its services from the economic balance sheets of producers and consumers. The proximate causes of the degradation include: widespread conversion of natural ecosystems to high-intensity human uses; exploitation, beyond sustainable yield, of commercially valuable wild plants and animals; introduction of invasive organisms that crowd out or otherwise kill off indigenous ones; emissions and spillovers of ecologically harmful substances from industry and agriculture; and, most recently, the growing impacts of global climate change resulting from heat-trapping gases and particles added to the atmosphere by human activities.

All of these proximate causes have been important—in varying combinations, places, and times—in biodiversity loss and other forms of ecosystem degradation up to the present, and all of them will continue to need remedial attention going forward if further ecosystem-service losses are to be prevented from causing harm ranging from costly to catastrophic to a wide variety of environment-linked dimensions of human well-being, in a wide variety of places. But the last-mentioned cause—anthropogenic global climate change—is clearly emerging as the single most dangerous and pervasive threat of all to ecosystems and the flows of ecosystem services around the world. If climate change is not slowed, much of the benefit from other kinds of efforts to protect environmental capital and the services flowing from it will be lost.

The Role of Government

These are challenges that cannot be met without a strong helping hand from government. The main reason is the set of perverse incentives for private decision-makers—firms and individuals—in relation to ecosystems and ecosystem services when government does not intervene. In the absence of such intervention, Individuals and firms are able to capture the benefits of activities that produce climate change and other forms of ecosystem disruption but are able to avoid most of the attendant damages, which are spread across society. Much of the world's environmental capital, moreover, consists of common-property resources rather than privately held assets; in part because of free-rider problems, private firms and individuals have little incentive, absent requirements imposed by government, to invest in maintaining or growing capital of this kind.

The result of the largely unfettered operation of this set of incentives should not be surprising. Over the past two and a half centuries, in concert with the rising demands of growing economies and the increasing power of technology to harvest from nature what people want and will pay for, the production of food, fiber, fuel, and pharmaceuticals from ecosystems has gone up, while most other services derived from ecosystems have gone down in parallel with the quantity and quality of the environmental capital from which those benefits flow. Society has gotten what it paid for. Now what is required is an increase in collective action—enlightened intervention by governments on society's behalf—if it is to avoid getting less and less of the environmental public goods it also needs.

The tools available to governments for this purpose are of two kinds. The first consists of measures that change the incentives of private actors in relation to their use of or impact upon environmental resources. These can include market-based measures that make the users of environmental services pay for them and exact compensation from those who consume or degrade environmental capital. They can also include standards and other forms of regulation to affect the relevant behavior of firms and individuals. (The market-based measures are widely agreed to be preferable where they are feasible, inasmuch as they tend to produce the desired results at lower cost than "command-and-control" approaches.) The second set of tools consists of direct action by governments in relation to ecosystems under their control (e.g., parks, national forests, other public lands, territorial waters), including acquiring additional ones, restoring degraded ones, protecting pristine ones, and managing those subject to multiple uses so as to maximize benefit flows consistent with sustainability.

The use, by governments, of tools in both of these categories would be greatly facilitated by the availability of complete information about the relationship between ecosystem condition (including but not limited to biodiversity) and ecosystem services, as well as about different measures of the value of those services to human society (included but not limited to the cost of replacing the services with technology where this is practicable and the damages accruing from reductions in the services that, for lack of available substitutes or failure to deploy them, do not get replaced). Of course, the information actually available on these topics is far from complete. But it is also far, far more than none at all. The government's capacity to appropriately influence the behavior of private actors toward environmental capital, as well as to better manage the environmental capital that is directly under the government's control, can be improved both by better use of available understandings, models, and data on these matters, and by focused efforts to upgrade the relevant understandings, models, and databases over time.

PCAST's Working Group on Biodiversity Preservation and Ecosystem Sustainability has addressed the needs and opportunities in relation to both of these dimensions of the capacity of governments—and especially the U.S. Federal government—to fulfill more effectively their responsibility in relation to the protection of environmental capital and ecosystem services. We note that this responsibility was made particularly explicit, for U.S. Federal departments and agencies, in the July 2010 guidance from the Directors of OMB and OSTP about reflecting the President's priorities in their FY2012 budget submissions, which called for "managing the competing demands on land, fresh water, and the oceans for the production of food, fiber, biofuels, and ecosystem services based on sustainability and biodiversity."

The Working Group's recommendations in support of this aim are grouped into three clusters: (1) making better use of existing knowledge, (2) generating essential new knowledge, and (3) expanding the use of evolving informatics technologies.

Making Better Use of Existing Knowledge

Much is known about how ecosystems function, how they can be degraded, and how they can be restored. Many Federal agencies, such as the EPA, USDA, NOAA, and the bureaus of the DOI, perform ecological monitoring and assessment of ecosystem services, and to a lesser extent biodiversity inventory. Likewise, many universities, non-governmental organizations, museums, botanical gardens, and other not-for-profit institutions have put substantial effort into species discovery, biodiversity inventory, environmental measurement, and investigations into the processes that generate and sustain ecosystems and biodiversity. Most of the data collected by these efforts reside in the collecting entities, however, and are not readily available or aggregated across sectors, agencies, and regions. And while the data document particular trends, they are not integrated in ways that can provide information on the condition and sustainability of the Nation's biodiversity and ecosystems as a whole.

To help make better use of the knowledge that exists to inform and guide national, regional, and sectoral policies and management and to contribute to global understanding of ecosystem change, we recommend the following:

- **The U.S. government should institute and fund a Quadrennial Ecosystems Services Trends (QuEST) Assessment,** that will provide:
  - Up-to-date syntheses of research findings on how ecosystem structure and condition are linked to the ecosystem functions that contribute to societally important ecosystem services, as well as research findings on the characterization and valuation of those services;

  - Integrated Information on the condition of U.S. ecosystems, including but not limited to their biodiversity, as well as on measures of ecosystem services flowing from them and the contributions of these to human health, economies, and other aspects of well-being;
  - Assessment of trends in these factors and scenarios of their evolution going forward under a range of assumptions about driving forces and management strategies and policies; and
  - Application of the foregoing information to identify and characterize challenges to the sustainability of the benefit flows from U.S. ecosystems, together with ways to make the policy responses to these challenges more effective.

The QuEST assessment should draw and build upon the wide variety of ongoing monitoring programs, as well as on the expanded monitoring and species-discovery efforts we call for elsewhere here. It should draw as well on previously conducted and ongoing assessments of narrower scope and should be closely coordinated with the quadrennial National Climate Assessment mandated by the Global Change Research Act of 1990.

Federal agencies collectively currently spend more than $10 billion annually on restoration activities, land and easement purchases, and incentive payments aimed primarily at conserving biodiversity or protecting and restoring ecosystem services within the United States. Notable examples of such conservation investments are annual expenditures of nearly $6 billion under the Farm Bill to improve water quality, reduce soil erosion, and protect wildlife habitat; $3.8 billion in mitigation costs under major federal regulatory programs; nearly $1 billion for endangered species recovery; and up to $900 million under the Land and Water Conservation Fund to acquire land and water and conservation easements (although this has been funded at less than $200 million annually in recent years).

While additional funding for these conservation investments is warranted, more careful targeting could achieve greater environmental benefits at the same level of expenditures. The allocation of much Federal conservation funding currently is based on factors other than an expected conservation benefit. In many cases, in fact, federal legislation explicitly mandates distribution of conservation funding not to achieve maximum conservation benefits, but rather by sector or geographic distribution. In other cases, agencies have the discretion to target resources based on expected effectiveness of the investment, but lack the expertise or the mandate to do so. Accordingly, we recommend that:

- **Federal agencies that implement biodiversity and ecosystem conservation programs should prioritize expenditures based on cost efficiency.** The Council on Environmental Quality should assist in this effort by reviewing conservation programs and identifying those that should be subject to this recommendation (e.g., Title 2 Farm Bill payments, mitigation payments, etc.). The affected agencies would report annually on the alignment of expenditures in the indicated programs with this metric. Their reports should indicate: (1) why they use a particular method for determining investment effectiveness; (2) how the methodology takes account of additionality, leakage, and potentially countervailing actions by other government programs; (3) the rationale for weightings used in aggregate indices; and (4) the status and results of their monitoring of their qualifying programs.

The degradation of ecosystems and reductions in the services that flow from them are subtracting from human well-being not just in the United States but all across the globe, and the universality of challenges of this character—notwithstanding differences in the mix of problems and their degree—provides reason for sharing information about them and comparing notes on the approaches being tried for dealing with them. In the case of problems in which causes in one country produce effects in others, moreover, there is further reason for international collaboration to understand the dynamics and develop cooperative remedies. Problems that degrade environmental capital in which all nations have a stake—the global climate, the protective layer of ozone in the stratosphere, the totality of biodiversity on the planet—are particularly demanding of international cooperation and coordination, all the more so because for most such problems the distribution of risk and loss is not well correlated with the distribution of the causes.

These reasons for collective concern, information sharing, joint study, and cooperative action have been reflected in the creation of numerous international organizations (e.g., the United Nations (UN) Environment Program, the Group on Earth Observations, the World Meteorological Organization, the International Union for the Conservation of Nature) and agreements (the Biodiversity Convention, the Montreal Protocol, the UN Framework Convention on Climate Change), as well as global ecological assessments and research initiatives (e.g., DIVERSITAS, the Millennium Ecosystem Assessment and follow-ups to it, the International Geosphere-Biosphere Program, the International Human Dimensions of Global Environmental Change Program, the Intergovernmental Panel on Climate Change, and the recently proposed Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). The United States government needs to up its game in support of these efforts. Accordingly, we recommend the following:

- **The U.S. Department of State, in coordination with the Office of Science and Technology Policy (OSTP), should take a leading role in the development of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES),** with the aim providing regular, thematic, global assessments of biosphere change, as well as preliminary assessments of emerging issues. The U.S. contribution to IPBES should be derived from and coordinated with the U.S. QuEST Assessment described above. Long-term oversight of this effort could be assigned to the Committee on International Science, Engineering, and Technology of the National Science and Technology Council (NSTC); the Sustainability Task Force of the NSTC's Committee on Environment, Natural, Resources, and Sustainability (CENRS); or a working group created between the Department of State and CENRS.
- **Under the leadership of OSTP and the US Global Change Research Program (USGCRP), the Federal Government should work with the International Council for Science (ICSU) and other partners to strengthen the component of international global-change research focused on ecosystem services and their sustainability.** In this connection, the United States should continue to support and provide data and expertise to the Group on Earth Observations (GEO) and its Biodiversity Observation Network (GEO BON), the Global Ocean Observing System (GOOS), and the Global Biodiversity Information Facility (GBIF), among other initiatives. It will also be important to establish beneficial feedback loops among these international initiatives and the National Ecosystem Services Assessment and other national activities; this is most easily accomplished through the adoption of common information standards and protocols.

Generating Essential New Knowledge

Improving understanding of how ecosystems function and provide benefits will require continued growth in knowledge about the species involved in those functions and benefits—which species are present, which are essential, and which are unique. This knowledge will assist not only with conserving and restoring ecosystem services but also with assessing the uses the genetic information in these species may have in farming, medicine, energy, industry, and other applications. The emphasis in work to identify more species and determine what they and those already known actually do in relation to ecosystem function should be on the groups of organisms likely to be most important in ecological terms, such as species that determine soil fertility, promote nutrient cycling, or consume wastes. In terrestrial environments, many such organisms of high ecological and economic importance are among the least familiar and least visible—e.g., fungi, nematodes, mites, insects, and bacteria. Populations of ecologically dominant marine organisms, most of which are either invertebrates or microbes, are just as poorly understood.

Given the pace and scope of environmental change, monitoring of biodiversity and other ecological parameters must be frequent and comprehensive, spanning spatial scales from local to global. The U.S. capacity for monitoring and reporting on environmental trends is large (although recent budget cuts are causing reductions) and highly professional, but it is also distributed among agencies to an extent that reduces its overall effectiveness. This fragmented system weakens attempts to implement national monitoring priorities. This lack, along with the inadequate spatial resolution and insufficiently frequent sampling in many agency programs, inhibits the monitoring of biodiversity and other ecosystem attributes that is needed to address issues of compliance, assessment, and management. We recommend:

- **In-depth sampling and inventory of critically important groups of organisms, including pathogens, at Federal-agency and federally funded research and monitoring sites should be commissioned and funded at increased levels by NSF, EPA, NASA, NOAA, DOI, and USDA, as appropriate.** Building on surveys already carried out by DOI bureaus, NOAA, NSF investigators, the Smithsonian Institution, and public and private organizations such as NatureServe, key gaps in species inventories should be identified by the CENRS and a strategy devised to fill them. The annual OMB-OSTP budget memo could call out these critical gaps as a priority for future funding and direct that the accumulating information be made available through the informatics coordinating entity described below.
- **The Committee on Environment and Natural Resources Research Sustainability (CENRS) of the NSTC should identify the most important data gaps within existing Federal and regional monitoring systems for biodiversity and other ecosystem attributes and clarify priorities and agency roles and funding for filling these. Further, OSTP and CEQ with the help of the NSTC should encourage and coordinate cross-scale and cross-agency collaboration in monitoring.** There are a number of key areas in which such collaboration in monitoring could rapidly improve the information base available for assessment and management. Among other dimensions of such collaboration, recommendations should be developed for integrating the existing monitoring networks with the help of state-of-the art informatics (see below for further information).

The capacity to develop scenarios and to make predictions of ecosystem change is necessary to develop strategies for the sustainable management of complex systems. Scientists have developed ever-improving models of ecosystems for this purpose, benefitting from the geo- and biophysical data gathered by earth-orbiting satellites as well as by in-situ measurements. Most of these models, however, have not yet fully incorporated data on human behaviors that affect ecosystems, including changing demographics, suburbanization, and changing agricultural and forestry practices. Instead, human behavior is treated as an exogenous driver of environmental change; neither the decision process nor the way that decisions change in response to feedbacks from the physical system is actually modeled.

Continuing improvement of ecosystem management going forward will require increasingly integrated models that include information on economic, political, social, and environmental determinants of societal activities and the feedbacks between those activities and environmental change. To date, integrated models have been used to evaluate regional environmental-management options in several parts of the United States, including the Gulf of Mexico, Chesapeake Bay, Puget Sound, and Great Lakes, but this has not been done at the national scale. We recommend the following:

- **CEQ should require Federal agencies whose missions include ecosystem management or regulation to identify and report on categories of human activities that significantly alter ecosystem structure and function and therefore services.** Such agencies include the Natural Resource Conservation Service, the Forest Service, and other services of the Department of Agriculture; the bureaus of the Department of Interior; the Army Corps of Engineers (DOD); and NOAA (DOC). The agencies should be encouraged to identify and report on trends in the factors and drivers (access rules, zoning restrictions, prices, etc.) associated with the reported activities.
- **The informatics entity (EcoINFORMA) proposed in the Working Group report should develop means to integrate the socio-economic data developed by the agencies with biological, geophysical, and Earth observation data.** Ground-based, spatially explicit observations of socio-economic causes and consequences of ecosystem change should complement space-based observations. These should include information about trends in demography, trade, economic incentives, subsidies, and related fields. The data and the information architecture developed should be made available to international networks (see below) to assist in the development of a global system of social markers of ecological change for use in ecosystem modeling.
- **OSTP, working with OMB and the NSTC, should promote further development of the capacity to predict environmental impacts of decisions by strongly encouraging interdisciplinary research that combines economics and sociology with biology and ecology, as well as developing means to analyze trade-offs.** The complex, human-natural environmental systems that must be managed for sustainability and well-being require breadth of understanding and multi-factorial approaches.

Market value plays a major role in the production of certain types of ecosystem services such as food (plant crops and fisheries), fuel (wood, liquid biofuels), and fiber (clothing and building materials). The ecosystem costs that are accrued through such production are usually incompletely considered, however, or more often ignored altogether. Other ecosystem services that are essential public benefits, such as the contributions of watershed vegetation to water quality and flood control, are completely outside markets and therefore are also not accounted for in economic terms. Such undervaluation of ecosystem services inevitably leads over time to deterioration of ecosystems and their services through exploitation without compensatory maintenance.

Progress in both ecology and environmental economics in recent decades has considerably bolstered the natural-science and social-science basis for valuation of ecosystem services and has led to the emergence of a range of techniques for doing so. These will never be comprehensive or completely accurate, but neither, it must be said, are the tools in everyday use for monitoring and forecasting the familiar measures of economic activity such as the GDP of a nation or the balance sheet of a firm. The issue is not perfection but usefulness; and continuing to improve the techniques for valuation of ecosystem services and applying those techniques in ways that incorporate the values derived into public and private decision-making affecting ecosystems can be very useful indeed in ensuring the preservation of this valuable environmental capital and the sustainability of the services flowing from it. We recommend

- **Federal agencies with responsibilities relating to ecosystems and their services (e.g., EPA, NOAA, DOI, USDA) should be tasked with using best available techniques to develop valuations for the ecosystem services affected by their decision-making and factoring the results into analyses that inform their major planning and management decisions.** This will entail expanding current efforts on ecosystem-service valuation in EPA, USDA, and other agencies, as well as generating new knowledge about the ecosystem-service impacts (in both physical and value terms) of activities taking place on both public and private lands.
- **The U.S. Bureau of Economic Analysis should renew efforts to develop satellite resource accounts to record changes in the quantity and value of ecosystem services provided by terrestrial and marine ecosystems.** Doing so will obviously entail the integration of inputs originating from many Federal as well as state and local agencies and spanning multiple disciplines. The effort will benefit from drawing upon the QuEST assessments called for above and the informatics developments described below.

Expanding the Use of Evolving Informatics Technologies

The collection of data is an essential first step in the powerful and rapidly developing new field of informatics, a term that refers broadly to the mathematical and computing techniques used to glean new understanding from the increasingly massive volume of data available in the natural and social sciences, humanities, medicine, engineering, business, law, and other domains. The power of these techniques for deriving insights about the relationships among biodiversity, other ecosystem attributes, ecosystem services, and human activities is potentially transformative.

The challenges in developing and applying informatics technologies in this domain are commensurate with the potential. They begin with the extreme heterogeneity of the data, which come from disparate disciplines and, within environmental science, from multiple kinds of monitoring platforms, both ground-based and remote, at many different observational scales and for many different time periods. An informatics infrastructure to deal with all this must embody mechanisms for making data openly and promptly available in formats accessible to both human and machine users; standards that permit interoperability, which must be embraced by all participating sectors; and decision-support software incorporating insights from—and responsive to the needs of—government, industry, and academia. We recommend:

- **The OMB should enforce existing requirements that Federal agencies publish data related to biodiversity preservation and ecosystem services within one year of collection.** Enforcement would require no new standards, but can be achieved through application of language already specified in the America Competes Act of 2007 and the Open Government Directive.
- **A facilitating and coordinating entity or initiative should be established by OSTP and NSTC to develop informatics capabilities that will serve all biodiversity and ecosystems-relevant agencies, national and regional assessments, and other integrative activities.** This effort would be called EcoINFORMA (Ecoinformatics-based Open Resources and Machine Accessibility) and would promote the development of informatics capabilities that enable biological, ecological, socio-economic and health data to be used together to assess impacts, and evaluate management responses. This facilitating entity would also serve a bridging function between the federal government and other sectors of the community. This collaboration will lead to the common standards and protocols needed to promote development of new tools.
- **EcoINFORMA should seek out and encourage partnerships with the private and academic sectors to maximize financial savings and develop innovative tools for data integration, analysis, visualization and decision making.** Though government agencies have the most pressing need of the decision-support tools described above, the academic and private sectors are most likely to have the innovation capacity needed for tools development. The tools that are needed will have voracious appetites for data, which the government sector is best able to provide. As agencies are inspired to collaborate by the complex challenges of our time, cost efficiencies are most likely when two or more agencies partner with private and academic entities to develop tools that will serve all partners, as well as the general public.

I. Introduction: Environmental Capital, Biodiversity, and Human Well-Being

The tremendous natural wealth with which the United States has been endowed contributes greatly to its strength and prosperity and remains the foundation for the well-being of current and future citizens. This wealth exists in the form of fertile land, abundant fresh water, a diversity of biological species adapted to many different ecological habitats, productive forests, fisheries and grasslands, and favorable climatic conditions. From these, society derives an array of important life support goods and services, including medicine, clothing, shelter, agricultural products, seafood, timber, clean air and water, and flood control. The natural wealth from which these goods and services arise is a capital asset of enormous magnitude.[1]

In the 1998 report, *Teaming with Life: Investing in Science to Understand and Use America's Living Capital*, President Clinton's Council of Advisors on Science and Technology (PCAST) summarized the case that ecosystems and the biodiversity they embody constitute environmental capital on which the well-being of society depends in multifaceted ways. The report noted further that high rates of ecosystem destruction and biodiversity loss in this country and around the world were already imperiling human health and welfare and would ultimately undermine national economies and international security. It attributed these high rates of destruction and loss to the combined pressure of population growth, rising affluence, and environmentally disruptive technologies, compounded by bad management attributable in substantial part to ignorance of the importance of environmental capital for human well-being and to its absence from the economic balance sheets of producers and consumers.

The 1998 report went on to offer a quite comprehensive set of concrete recommendations for how the U.S. government could lead this country toward more effectively protecting and managing its ecological assets. The recommendations were divided into five broad categories: (1) making better use, in ecosystem and biodiversity management, of existing scientific understandings; (2) increasing investments in assessment, monitoring, and research to improve the knowledge base for such management going forward; (3) building a next-generation information infrastructure for U.S. ecological data; (4) expanding and deepening efforts to characterize, quantify, and, where practical, monetize the benefit flows from ecosystems to society, to improve the basis for management decisions and to facilitate the development of markets and market-like mechanisms for incorporating ecosystem values into economic decision-making where this can be done; and (5) strengthening efforts in formal and informal education about ecology, biodiversity, and ecosystem services, as a basis for the public understanding and political support needed for adequate action.

1. PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

BOX I-1: ECOLOGICAL TERMINOLOGY

An **ecosystem** is a co-existing set of species and their habitat, generally characterized by a particular climatic regime and other physical conditions (e.g., soil types on land, water depths and substrates in freshwater and marine environments) as well as by the set of species present.

Biodiversity refers to all forms of variability among living organisms, including the number of species, the genetic diversity found within species and in their totality, and the diversity of types of ecosystems. Depictions of the diversity among and within species may refer to a particular ecosystem, or set of ecosystems (such as all the marine ecosystems, together making up the oceans), or a physical space ranging in size from the body of a fly to the entire globe.

Ecosystem processes are interactions among species and between species and the nonliving parts of their environment that entail transfers, transformations, and storage of energy and materials. Ecosystem processes include photosynthesis and evapotranspiration by plants, herbivory and predation by animals, decomposition by bacteria and a variety of other creatures, respiration by organisms of all kinds, and many forms of competition and mutualism.

Ecosystem services are results of ecosystem processes that confer benefits on human society. Examples include formation of soil and the maintenance of its fertility by means of the recycling of chemical nutrients; management of flows of fresh water (including the flood-control functions of forests); purification of air, water, and soil; pollination of flowers and crops; controls on the distribution and abundance of pests and pathogens; production of fish and game; and contributions to the maintenance of climatic conditions within ranges to which existing ecosystems and human societies are adapted (through, for example, evapotranspiration, effects on surface reflectivity, and storage of carbon that otherwise would be adding to the CO_2 load in the atmosphere).

Now, more than a decade later, the Working Group on Biodiversity Preservation and Ecosystem Sustainability (BPES) constituted under President Obama's PCAST has considered what a dozen more years of experience, observation, and advances in ecosystem science can tell us today about status and trends in the condition of ecosystems and biodiversity here and abroad; about successes and failures in the attempts of the past decade to strengthen the mechanisms and institutions of biodiversity protection and ecosystem management; and about what an updated set of recommendations for U.S. government action should contain. In this introductory chapter we introduce the ecosystem concepts and terminology that will be used throughout the report, place the concept of environmental capital in larger context, summarize recent assessments of the state of ecosystems in the United States and around the world, discuss the role of government in addressing the associated challenges, and review the capabilities for valuation of ecosystem services. We close with a roadmap of the rest of the report.

Ecosystem Terminology and Concepts

The terms "ecosystem," "biodiversity," "ecosystem processes," and "ecosystem services" are concisely defined in Box I-1. While these definitions are reasonably straightforward, the relationships linking the biodiversity in an ecosystem with the processes that go on there and the services performed for society are not: they are complex and not completely understood. In particular, not all of the biodiversity in a given ecosystem is necessarily essential to the current ecosystem processes responsible for that ecosystem's services.

From the standpoint of an ecosystem's functioning, some of the biodiversity present evidently serves to provide resilience for an inherently uncertain future, insofar as characteristics in the gene pool that are not needed now could become valuable or even indispensable under different conditions. It is known that co-evolved biodiversity—diversity among and within species that have co-existed over a long time—confers a degree of stability in ecosystem composition and function; conversely, introduced biodiversity in the form of invasive species can be highly destabilizing, leading to sharp reductions in ecosystem services over time.

In principle, the dimension of biodiversity that is easiest to quantify and to grasp is the number of species present, but even this is extremely difficult to pin down in practice. Recent estimates of the number of species on Earth range from 5 million to 100 million. The number so far identified and named is about 1.9 million—thus somewhere between 2% and 40% of those that may exist. Of the named ones, about 1,000,000 are insects, 320,000 are plants, 30,000 are fish, 10,000 are birds, and 5,500 are mammals (among other categories). It is likely that the vast majority of those not yet identified and named will prove to be microorganisms. It should be cause for concern that scientific knowledge of what microorganisms exist and what they are doing is so sparse, given that human activities are affecting temperature, moisture, and the chemical environment—conditions capable of affecting the relative abundances and functions of different species of microbes—over large swaths of the planet.

Certainly, the gaps in scientific understanding of biodiversity and the roles it plays in ecosystem processes and services contribute to the difficulty of characterizing and quantifying the damage to human well-being from past, present, and future impacts of human activity on ecosystems. But this incompleteness of understanding, while ample cause for increased investments in the research needed to reduce it, can hardly be cause for complacency about those impacts in the meantime. For one thing, as will be noted below, there is already more than enough quantitative information about some of the damages from extreme ecosystem disruption—e.g., clear-cutting of forests, filling of estuaries, overfishing commercial species to near extinction, toxic contamination of lakes and streams—to be cause for alarm. For another, it is clear, even in the absence of understanding of the details, that removing biodiversity from ecosystems is inherently a risky business and must eventually lead to impairment of aspects of ecosystem condition and performance that matter for ecosystem services.

Environmental Capital in Context

Human well-being depends on capital of three kinds and the goods and services that flow from these:

- **Economic capital**, from which flows jobs, income, durable and perishable goods, and a wide variety of purchased services;
- **Sociopolitical capital**, which produces and is sustained by educated and healthy citizens enjoying political freedoms and participation, personal and national security, a social safety net, a functional and equitable system of justice, reasonable privacy, and access to culture and the arts; and

- **Environmental capital**, in the form of the ecosystems and supporting geophysical conditions and processes that maintain the composition of the atmosphere and oceans, keep the surface temperatures over most of planet, for most of the time, within a range conducive to human life and productive activity, and provide the other ecosystem services mentioned above.

These three kinds of capital—economic, sociopolitical, and environmental—cannot sensibly be ranked in importance because all three are absolutely indispensable, and they are completely interdependent. For example, economic and environmental capital work together in food production; a properly functioning economy requires many forms of sociopolitical and environmental capital; the capacity to invest in sociopolitical and environmental capital depends on the strength of the economy; and sociopolitical, economic, and environmental capital together shape human health outcomes. Economic and sociopolitical capital alike are vulnerable to destruction by environmental disasters ranging from the local (Hurricane Katrina, the Haitian earthquake, and the Japanese tsunami and earthquake) to the global (extreme climate disruption).

The three categories of capital are only partially substitutable. In particular, and most importantly for our topic here, only within certain circumstances and limits can additions to economic capital compensate for losses from the stock of environmental capital. Yes, industrial fertilizers can partly offset shortfalls in the natural fertility of soil; industrial pesticides can partly offset the loss of natural controls on crop pests; and dams can partly offset the loss of natural flood-control benefits from previously forested landscapes that have been denuded. But limits on technological replacements for ecosystem services arise from problems of cost, scale, and unwanted side effects, as well as, in many cases, lack of either the scientific understanding or the technological capability to replace what ecosystems do.

Given the indispensability, interdependence, and limited substitutability of the three forms of capital, it follows that societal well-being cannot be sustainably advanced through strategies that do not protect and enhance all three in a balanced manner. Put another way, it is counterproductive to pursue improvement in one or two of the three dimensions of well-being without paying adequate attention to the indispensable elements of one or both of the other dimensions. Most specifically for our purposes here, if improvements in the economic dimension of well-being from economic growth are to be sustainable, they must not be achieved in ways that seriously erode the sociopolitical and/or environmental dimensions; investments (of policy considerations and research, as well as money) must be made in the sociopolitical and environmental dimensions in order for the economy to thrive.

U.S. and Global Environmental Capital: Dimensions and Dangers of Decline

Beyond the foregoing fundamental understandings about what environmental capital is and what it contributes to human well-being, it's important to know what contemporary science has to say about the condition of that capital and how it has changed and continues to change over time, as well as which services that flow from it are being impacted, and to what degree. The Introduction to the 1998 PCAST report[2] summarized these matters at that time:

2. PCAST(1998). Teaming with life: Investing in science to understand and use America's living capital. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

> *With industrialization and the development of modern technologies, the human species has emerged as the dominant force on the planet. We have wrought massive changes that rival or exceed those caused by natural biological and geological processes. While human impacts were once local and reversible, they are increasingly becoming global and much less reversible. The collective activities of American society are changing the chemistry of land, water, and atmosphere far more dramatically than are natural processes. It is already apparent that some of these changes are adversely affecting our natural capital3 and its ability to support us sustainably.*
>
> *Collectively, all human beings, including Americans, are playing a crucial role in the sixth major extinction event to occur in the course of more than three billion years of life on Earth, and the first in the past 65 million years. Species are being driven to extinction thousands of times faster than new ones can evolve.*
>
> *Past and current usage practices have disturbed ecosystems and threatened ecosystem services. For example, urban and suburban development of watersheds has been detrimental to natural water purification by ecosystems at a time when human populations are growing and needing more water. Overuse of and excess application of chemicals to soils have disrupted natural processes. Habitat loss, air pollution and chemical pesticides have reduced populations of natural pollinators and natural control agents for agricultural pests. Overfishing and agricultural runoff have diminished marine biodiversity and increased the frequency of toxic algal blooms that cause poisoning of economically valuable fish and shellfish. . . .*
>
> *The dramatic deterioration of the natural capital of the United States already has had major economic and social consequences. . . . For example, land-use changes have seriously compromised the effectiveness of natural water purification processes, which in turn has imposed massive capital costs on many communities. More than one-third of our agricultural soils have been lost to erosion and unsustainable agricultural practices. Decimation of pollinating insects has imposed large costs on agriculture. Deterioration of wetlands and other natural aspects of drainages has left communities vulnerable to flooding and mud slides. . . Population explosions of harmful algae have destroyed or seriously impaired fisheries and recreational opportunities and created human health hazards. . . .*

The *Teaming with Life* study was far from the first to take note of such changes, of course. A concise guide to the century and a half of scientific literature prior to 1998 on the effects of human activities on ecosystems is provided in Box I-2. The 1998 PCAST authors thus had a substantial body of data and analysis on which to base their conclusions about the condition of—and human influences upon—ecosystems and biodiversity historically and up to the time of writing. But they were also quick to point out large gaps in the available data and understandings about biodiversity, ecosystem function, and ecosystem services, and many of the report's recommendations focused on ways to shrink those gaps in knowledge.

3. Called "Environmental capital" in this report.

BOX I-2: THE PRE-1998 LITERATURE OF ECOSYSTEM IMPACTS

Leaving aside Greek and Roman writers who documented local consequences of deforestation and overgrazing, the precursors of modern studies of human impacts at continental and global scale were George Perkins Marsh's Man and Nature in 1864 and his *The Earth as Modified by Human Action* a decade later. Subsequent scholarly landmarks that guided PCAST's 1998 product included the 1956 symposium volume, *Man's Role in Changing the Face of the Earth*; the report of MIT's 1970 summer study entitled *Man's Impact on the Global Environment*; the massive 1990 compendium entitled *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*; the UN Environment Program's 1995 *Global Biodiversity Assessment*; the 1995 Second Assessment of the Intergovernmental Panel on Climate Change; and the 1997 volume, *Nature's Services: Societal Dependence on Natural Ecosystems*—this in addition to a large and rapidly growing mountain of peer-reviewed articles on Earth-system science (including geology, geography, geochemistry, climatology, ecology, population genetics, and ecological economics).

Sources

Marsh, G. P. (1864). *Man and nature.* New York, NY: Charles Scribner.

Marsh, G. P. (1877). *The Earth as modified by human action.* New York, NY: Scribner, Armstrong & Co.

Thomas, W. L. (Ed.). (1956). *Man's role in changing the face of the Earth.* Chicaco, IL: University of Chicago Press.

The Study of Critical Environmental Problems. (1970). *Man's impact on the global environment: Assessment and recommendations for action.* Cambridge, MA: MIT Press.

Turner II, B. L., Clark, W. C., Kates, R. W., Richards, J. F., Mathews, J. T., & Meyer, W. B. (Eds.). (1990). *The Earth as transformed by human action: Global and regional changes in the biosphere over the past 300 years.* Cambridge: Cambridge University Press.

UN Environment Programme. (1995). *Global biodiversity assessment.* Cambridge: Cambridge University Press
Intergovernmental Panel on Climate Change (IPCC). (1995). *IPCC second assessment: Climate change (1995).* Retrieved from http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf

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

A historically unprecedented amount of effort—in the United States, in other countries, and in international projects—has been devoted since 1998 to filling those gaps. There have been important advances in virtually every branch of science germane to this set of issues, assisted by enormous progress in the capabilities of Earth-observation satellites and the information technology for storing, transmitting, and manipulating large environmental datasets. In addition, the discipline of interdisciplinary assessment of complex environment-and-society issues by teams of scores to hundreds of experts from across the United States or around the globe has advanced tremendously. And yet, one of the most important things that has been learned is how much we have yet to learn.

Nonetheless, the monumental Millennium Ecosystem Assessment (MEA), which engaged over 1300 experts from 95 countries in the production of 12 major volumes under the overall title, *Ecosystems and Human Well-Being*,[4] tells us a great deal that can be used now and that can be built upon. Appearing between 2003 and 2005, these volumes synthesize the then-available knowledge about the state of the world's ecosystems, the services that flow from them, the extant and projected losses attributable to ecosystem disruption by human activity, possible policy responses, and approaches for improving the comprehensiveness and accuracy of such assessments in the future. The MEA developed a formal

4. Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: General synthesis.* Washington, DC: Island Press.

framework for thinking about ecosystem services that has been adopted by most studies since, and characterized more systematically than before the variations across ecosystems in the relative importance as well as the temporal trends in the five principal proximate causes of biodiversity loss—habitat change, invasive species, overexploitation, pollution, and climate change.

In the most quantitative depiction to date of the extent of ecosystem disruption globally by human activities, the MEA concluded that:

- More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850. Cultivated systems now cover one quarter of Earth's terrestrial surface.
- More than two thirds of the area of two of the world's 14 major terrestrial biomes (types of ecosystems) and more than half of the area of four other biomes had been converted by 1990, primarily to agriculture.
- Since 1960, flows of reactive (biologically available) nitrogen in terrestrial ecosystems have doubled, and flows of phosphorus have tripled.
- Approximately 20% of the world's coral reefs were lost and an additional 20% degraded in the last several decades of the twentieth century, and approximately 35% of mangrove area was lost during this time (in countries for which sufficient data exist, which encompass about half of the area of mangroves).
- Approximately 60% of the ecosystem services evaluated in the MEA are being degraded or used unsustainably. Ecosystem services that have been degraded over the past 50 years include capture fisheries, water supply, waste treatment and detoxification, water purification, natural hazard protection, regulation of air quality, regulation of regional and local climate, regulation of erosion, spiritual fulfillment, and aesthetic enjoyment.
- The use of two ecosystem services—capture fisheries and fresh water—is now well beyond levels that can be sustained even at current demands, much less future ones. The global marine fish catch peaked in the late 1980s and has been declining more or less steadily since, despite increases in fishing effort.
- Across a range of taxonomic groups, either the population size or range or both of the majority of species is currently declining.
- The rate of known extinctions of species in the past century is roughly 50–500 times greater than the extinction rate calculated from the fossil record of 0.1–1 extinctions per 1,000 species per 1,000 years. Some 10-30% of mammal, bird, and amphibian species are currently threatened with extinction.[5]

Four qualitative conclusions of the MEA are also particularly worthy of note:

- For ecosystem functions such as productivity and nutrient cycling, the level, constancy of the service, and resilience to shocks all decline over the long term if biodiversity declines.

5. Bullets abstracted from Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: General synthesis*. Washington, DC: Island Press, pp. 2-6.

- The preservation of genetic variation among crop species and their wild relatives and spatial heterogeneity in agricultural landscapes are considered necessary for the long-term viability of agriculture.
- The destabilizing effects of anthropogenic environmental change pose multiple serious threats to human well-being, including health.
- By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally.

The last conclusion has only been strengthened by the even more recent scientific literature on the pace of global climate change and its impact on ecosystems, particularly the reports of Working Group I (The Physical Science Basis[6]) and Working Group II (Impacts, Adaptation, and Vulnerability[7]) of the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change; the multi-author, multinational *Copenhagen Diagnosis 2009—Updating the World on the Latest Climate Science*[8]; the 2010 U.S. National Academies report, *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*[9]; and a spate of recent peer-reviewed scientific papers detailing connections between global climate change and ecosystem processes across a range of scales and environments.

The bottom lines from this recent literature are these: the atmospheric build-up of greenhouse gases, global-average surface-temperature increase, sea-ice shrinkage, ice loss from the Greenland and Antarctic land ice sheets, and sea-level rise have been proceeding at or above the high range of earlier projections; extreme weather and weather-related effects such as floods, droughts, heat waves, wildfires, and unusually powerful storms have variously been on the rise in many different parts of the globe, generally in patterns predicted to result from greenhouse-gas induced global climate change; and alterations in the geographic distribution, abundance, and reproductive behavior of hundreds of species around the world, consistent with the changes in climate being experienced in their regions, have now been documented. On the basis of this evidence it seems highly likely that climate change will be the dominant driver of biodiversity loss and disruption of ecosystem services not just by the end of the current century but much sooner.

Recent studies focused specifically on the United States have similarly offered mainly bad news about the growing impacts of human activities on this country's ecosystems and the likely further effects of climate change, especially, over the course of this century. The most comprehensive and quantitative recent assessment of current ecological conditions and trends in the United States is *The State of the*

6. IPCC. (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: Cambridge University Press

7. IPCC. (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: Cambridge University Press.

8. Allison, I., Bindoff, N. L., Bindschadler, R. A., Cox, P. M., de Noblet, N., England, M. H., . . . Weaver, A. J. (2009) *The Copenhagen diagnosis: Updating the world on the latest climate science.* Sydney, Australia: The University of New South Wales Climate Change Research Centre.

9. National Research Council, Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations. (2010). *Climate stabilization targets: Emissions, Concentrations, and impacts over decades to millennia.* Washington, DC: The National Academies Press

Nation's Ecosystems 2008[10], the 150-author, final report of a six-year project sponsored by The H. John Heinz III Center for Science, Economics, and the Environment. The authors found that:

- Nearly 60% of farmland streams had at least one pesticide at concentrations exceeding benchmarks for the protection of aquatic life, and about 16% had at least one pesticide at levels exceeding benchmarks for protection of human health.
- Half or more of the stream water, stream sediment, estuarine sediment, and freshwater fish tissue samples had at least one contaminant at concentrations above benchmarks set to protect aquatic life.
- The areas of the nation's freshwater and coastal wetlands have been decreasing, while the urban-suburban area has increased.
- One third of U.S. native terrestrial and freshwater aquatic species are at risk of extinction.

On the positive side, the Heinz report found that forested area in the United States has not been changing in recent decades, nor has the plant-growth index, and U.S. forests have lately been taking up carbon rather than losing it. It also found that available data were simply inadequate to characterize the current state or recent trends for many indicators of ecological health that ought to be monitored.

The most recent studies to attempt a comprehensive look at existing and potential impacts of climate change on the United States have been the U.S. Global Change Research Program's *Global Climate Change Impacts in the United States* (2009)[11] and, from the U.S. National Research Council's project on "America's Climate Choices," the report entitled *Adapting to the Impacts of Climate Change* (2010).[12] Key findings from these reports on current and projected impacts on ecosystems and ecosystem services include:

- Climate change has already altered the water cycle and will continue to do so, affecting where, when and how much water is available for all uses. Precipitation and runoff are likely to increase in the Northeast and Midwest in winter and spring, and decrease in the West, especially the Southwest, in spring and summer.
- Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change, and rainfall becomes more concentrated into heavy events (with longer, hotter dryer periods in between). Heavy downpours and droughts are likely to reduce crop yields.
- Weeds, diseases, and insect pests benefit from warming, and weeds also benefit from a higher carbon dioxide concentration, increasing stress on crop plants and requiring more attention to pest and weed control.

---

10. The H. John Heinz III Center for Science, Economics, and the Environment. (2008). *The state of the nation's ecosystems (2008): Measuring the land, waters, and living resources of the United States.* Washington, DC: Island Press

11. Karl, T.R., Melillo, J.M., & Peterson, T.C. (Eds.). (2009). *Global climate change impacts in the United States.* Cambridge, UK: Cambridge University Press. Retrieved from http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

12. National Research Council: America's Climate Choices. (2010). *Adapting to the impacts of climate change.* Washington, DC: The National Academies Press

- Deserts and dry lands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion.
- The multiple stresses already being experienced by coastal and near-shore ecosystems will be exacerbated by climate change and ocean acidification by CO_2 uptake from the atmosphere.
- Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and these shifts are very likely to continue. The habitats of some mountain species and coldwater fish, such as salmon and trout, are very likely to contract in response to warming.

Rationale for Government Leadership in the Stewardship of Environmental Capital

In earlier times it might have been argued that environmental capital maintains itself, through natural processes, without need for help from society. After all, it did so over countless millennia. But the manifest declines in the environmental capital stock that are now understood to have occurred since the Industrial Revolution—and most rapidly under the enormous growth in civilization's environmental impacts over the past hundred years—make clear that this is no longer the case. The investments in all three forms of capital needed to at least sustain, and where possible to increase, the flows of valuable goods and services they provide in support of human well-being must therefore come, in some combination, from firms, other nongovernmental organizations, individuals, and governments.

The investments of firms are made principally in forms of economic capital from which the expected flows of goods and services are well characterized, readily quantified, and predictably convertible into monetary flows to the investors. Individuals, similarly, tend to invest in economic and sociopolitical capital in forms from which they expect to realize direct and well characterized benefits for themselves and their families, even if those benefits are not always easily quantified or monetized (e.g., the benefits from investments made in one's children's education).

It falls then to governments—and, to a necessarily lesser extent given their more limited resources, to the philanthropic NGOs—to make the needed investments in those forms of capital, largely of the sociopolitical and environmental kinds, that are essential for societal well-being but are neglected by private investment because the associated flows of benefits have not been fully characterized, or are difficult to quantify, or resist monetization, or consist of public goods (those that accrue to all no matter who makes the investments that produce them), or a combination of these reasons.

A prime example, accepted by virtually all political persuasions, is the need for the government to invest in national defense. This investment yields an obvious public good, the benefits of which are relatively easy to characterize in terms of the kinds of harm that are avoided, but very resistant to quantification and monetization. (One can estimate, at any given time, what national defense *costs* in lives and in treasure, but no one can put a price on its benefits…nor even put a meaningful figure to the probability of disaster should the investment fall short.)

The nature of the need for government investment in environmental capital is similar to the national-defense case in some respects and different in others. In the way of similarities:

- The benefits flowing from environmental capital, like national defense, are public goods;
- Some of these benefits are indispensable, and many defy monetization;
- The thresholds of serious peril from under-investment are often highly uncertain; and
- The magnitude of the investments needed to secure everyday benefits as well as provide insurance against real catastrophe appears to be in the range of a few percent of GDP for environment and national defense alike (thus not by any stretch unaffordable given the indispensability of the services secured thereby).

In the way of differences:

- The varieties of capital and the benefits that flow from them are even more diverse in the case of environment than for national defense, and accordingly the protection and enhancement of environmental capital requires greater diversity in the investment vehicles and other measures used than in the case of defense;
- At least some environmental benefit flows are subject to quantification and monetization to a greater degree than are the benefits from national defense, opening the possibility of somewhat greater use of markets and market-like mechanisms to value and protect those benefits; and
- Understanding of the need for government investment in and other actions protective of environmental capital is far less pervasive among policy makers and the public than is the case for national defense, which means public and policy-maker education an essential element of mounting an adequate response to the need.

Valuation of Ecosystem Services and Losses

The 1998 PCAST report noted the particular challenges of quantifying, with any degree of precision, the flows of actual benefits to human well-being from ecosystem services, never mind the further step of attaching monetary values to these. They cited some rough estimates of monetary values nonetheless: for just the United States, annually, $100 billion from ecotourism; $85 billion in waste disposal and bioremediation of pollution by natural processes; $60 billion worth of soil formation; $40 billion worth of pollination services; perhaps $30 billion for the fraction of prescription pharmaceuticals that are based on plants, fungi, animals, and microorganisms; $20 billion in over the counter plant-based drugs; $17 billion worth of natural controls on crop and forest pests; $12 billion spent by hunters of wild animals; $8 billion in natural fixation of nitrogen; $8 billion in timber and fuel wood; $3-8 billion in other forest products; and $2.5 billion per year in this country's ocean fish catch.

Many of these estimates were clearly very approximate indeed, which the report acknowledged while calling for additional research to confirm or correct them and to improve the capacity to quantify and attribute monetary value to such services. Even if accepted as only the roughest and most incomplete account, however, numbers in this range suffice to illustrate that the total economic value associated with ecosystem services is significant. Of course, even knowing more precisely the economic value of those ecosystem services that lend themselves to monetization would not, in itself, provide insight into what fraction of the benefit would be lost in consequence of a given type or degree of ecosystem disruption. That, alas, is the information that would be most useful to have in order to design mechanisms for incorporating the value of ecological capital into market decisions. Obtaining this information will require, in many cases at least, a much more sophisticated understanding of the relations between ecosystem condition and ecosystem services than is currently at hand.

The MEA[13], the main reports from which were published in 2005, had considerably more published material about methods of valuation of ecosystem services—and application of those methods—to draw upon than had been available to the PCAST authors in 1998. Growing interest in ecological economics and the increasing amount of data available from the ecological side had led to significant progress in the intervening years, and the MEA summarized the then-current state of this domain in a manner both systematic and accessible. In addition to characterizing the wide range of economic valuation techniques that have been developed as to their approach, range of applicability, data requirements, and limitations, the MEA reports provided a wide variety of estimates of dollar values of ecosystem services, mostly local and regional rather than national or global. Some of these examples showed that the value of the directed marketed benefit flows from some ecosystems (such as timber and fuel-wood production from forests) can be considerably less than that of their non-marketed or only indirectly marketed flows (such as watershed protection, recreation, and carbon sequestration).

Still more up-to-date presentations of the valuation issue have recently been provided by the United Nations Environment Program (UNEP) led international project on The Economics of Ecosystems and Biodiversity (TEEB), which in late 2010 released both a synthesis volume (*The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature*[14]) and a more detailed main report (*The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*[15]). In addition to surveying available approaches, this study applied them together with the MEA's taxonomy of types of ecosystem services to develop ranges of estimates of the values of services in the different MEA categories for each of the world's major productive biomes.

The results prove highly sensitive to the location of a particular ecosystem of a given type (which precludes simple "handbook" approaches to ecosystem-service valuation for real-world policy purposes). And a major limitation remains, the authors acknowledge, the lack of detailed understanding of how ecosystem condition and function relate to the provision of ecosystem services for many of the cases of interest (which means, as noted above, that knowing the value of a service does not confer knowledge of how much the value will be reduced by a given type and degree of ecosystem disruption).

13. Op. cit., p. 16.

14. Economics of Ecosystems and Biodiversity (TEEB) study. (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.* Retrieved from http://www.teebweb.org/TEEBSynthesisReport/tabid/29410/Default.aspx

15. Kumar, P. (Editor). (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations.* London: Earthscan. Retrieved from http://www.earthscan.co.uk/?tabid=102480

Learning more, over time, about valuation of ecosystem services and the losses that ensue from ecosystem disruption will improve *both* the ability to embed some of the value of environmental capital into private market decisions *and* into the decision-support tools available to managers of environmental resources who must deal with choices where markets will do not do the whole job. But it would be a mistake to assume that perfection in valuation is a pre-requisite for getting society to make adequate investments in the protection and replenishment of environmental capital.

It is in the nature of ecosystem services that valuation will always be only partial. And it does not need to be complete. After all, if society has found ways to muster the political will and the resources to invest adequately in national defense—not to mention other costly forms of sociopolitical capital whose benefit flows are difficult or impossible to quantify, never mind monetize—it cannot be considered an insurmountable obstacle to making adequate investments in environmental capital that its benefits, too, cannot be fully quantified and monetized.

The Rest of the Report

In the next chapter we turn to the direct effects of ecosystem change on human health, a domain in which new understandings have materialized at an especially rapid pace over the last decade or so. Chapter III then expands on the challenges and opportunities in constructing ecosystem assessments for predicting and adapting to change, and Chapter IV addresses the international dimensions of the assessment issue. Chapter V discusses ways to increase the effectiveness of conservation investments. Chapter VI treats the need for additional information about biodiversity and other ecosystem attributes, and Chapter VII discusses progress and prospects in the domain of valuation of ecosystem services. The final chapter examines how advances in the rapidly evolving field of informatics can be brought to bear to strengthen all of these efforts.

II. Direct Effects of Ecosystem Change on Human Health

One of the most obvious, direct, and often immediate effects of ecosystem change is the emergence of new diseases or the resurgence of known disease, following ecological disturbance—one recent example being the outbreak of cholera following the earthquake in Haiti in 2010. Other disease emergences may be less rapid, and less obviously tied to a readily identifiable ecosystem change, but nonetheless are connected to it. The United States needs to strengthen its capacity to recognize and respond effectively to health threats that stem from ecological change, especially in the case of emerging infectious diseases, malnutrition, and disaster management, where awareness of ecosystem services and function can significantly inform disease prevention policies.

Ecosystem changes that result from human activities can trigger ecological mechanisms that increase the risk of human disease transmission. Alternatively, they can exacerbate conditions of vulnerability in the human population, such as malnutrition, stress and trauma (in floods and storms, for example), immunosuppression, or respiratory ailments associated with poor air quality. In recognition of these relationships, the *Millennium Ecosystem Assessment*[16] defined the "regulation of infectious diseases" as an ecosystem service, based on ample medical evidence:

- Deforestation increases the extent of breeding habitat of the principal malarial mosquito species in the Amazon region[17] and sub-Saharan Africa.[18]
- Variation in the risk of Lyme disease depends on changes in species composition of the mammalian community in northeastern U.S. forests, where the white-footed mouse is the main reservoir host for the causative bacterium. The presence of more non-mouse mammals—known as the "dilution effect"—reduces the likelihood of a tick becoming infected.[19] This benefit of greater biological diversity has also been described for a variety of other diseases, including West Nile virus,[20] hantavirus pulmonary syndrome,[21] and bartonellosis.[22]
- In Africa, the blood of bushmeat hunters who intrude into wilderness has been found to contain monkey "simian foamy virus," a retrovirus endemic in most Old World primates. The retrovirus

16. Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: General synthesis.* Washington, DC: Island Press.

17. Vittor, A. Y., Pan, W., Gilman, R. H., Tielsch, J., Glass, G. E., Shields, T., Patz, J.A. (2009). Linking deforestation to malaria in the Amazon: Characterization of the breeding habitat of the principal malaria vector, *Anopheles darlingi. American Journal of Tropical Medicine and Hygiene, 89,* 5-12.

18. Guerra, C. A., Snow, R. W., & Hay, S.I. (2006). A global assessment of closed forests, deforestation and malaria risk. *Annals of Tropical Medicine and Parasitology, 100,* 189-204.

19. Ostfeld, S. R., & Keesing, F. (2000). Biodiversity and disease risk: The case of Lyme disease. *Conservation Biology, 14,* 722-728.

20. Ezenwa, V. O., Godsey, M. S., King, R. J., & Guptill, S. C. (2006). Avian diversity and West Nile virus: testing associations between biodiversity and infectious disease risk. *Proceedings of the Royal Society B, 273,* 109-117.

21. Peixoto, I. D., & Abrahamson, G. (2006). The effect of biodiversity o n the hantavirus epizootic. *Ecology, 87,* 873-879.

22. Bai, Y., Kosoy, M. Y., Calisher, C. H., Cully, J. F., Jr., & Collinge, S. K. (2009). Effects of rodent community diversity and composition on prevalence of an endemic bacterial pathogen—*Bartonella. Biodiversity, 10,* 3-11.

causing HIV/AIDS was also highly likely to have been a mutated simian virus contracted through bushmeat hunting.[23]

In this chapter, we describe ecological reasons for the emergence of disease, some of the actions that have been taken or are available for assessment and mitigation, and recommend additional actions that will have a positive effect on the Nation's capacity to recognize and respond to emerging diseases that result from changes in ecosystems. History has taught humanity the consequences of failing to think broadly enough about the ecological consequences of our actions. Now that we know that ecological change is directly linked to challenges to human health and well-being, we must anticipate the long-term consequences of immediate actions.

Ecosystem Changes that Underlie Disease Emergence

The reasons for the emergence or reemergence of some diseases are unknown, but the following mechanisms and examples of underlying drivers have been identified as causes of change or increase in the incidence of many diseases:

- **Altered habitat**, which can lead to changes in the number of vector breeding sites or in disease reservoir host distribution.[24,25,26,27,28] Three types of drivers are primarily responsible for altered habitat: (1) destruction, conversion, or encroachment of wildlife habitat, particularly through deforestation and reforestation; (2) changes in agricultural land use, including proliferation of both livestock and crops; and (3) changes in the distribution and availability of surface waters, such as through dam construction, irrigation, and stream diversion.
- **Biodiversity change**, including loss of predator species and changes in host population density.[29] The main drivers of biodiversity change are the same as those that alter habitat, plus overharvesting (such as overfishing) and invasive species.
- **Niche invasion** or host-shifting by pathogens, the drivers of niche invasion include human migration, international travel and trade, and accidental or intentional introduction of pathogens by humans.

23. Hahn, B.H., Shaw, G.M., De Cock, K.M., & Sharp, P.M. (2000). AIDS as a zoonosis: scientific and public health implications. *Science, 287,* 607-614.

24. Olson S. H., Gangnon R., Silveira G., & Patz, J. A. (2010). Deforestation and malaria in Mâncio Lima County, Brazil. *Journal of Emerging Infectious Diseases, 16(7),* 1108-1115 doi: 10.3201/eid1607.091785. Retrieved from http://www.cdc.gov/EID/content/16/7/1108.htm

25. Olson, S. H., Gangnon, R., Elguero, E., Durieux, L., Guégan, J. -F., & Foley J. A. (2009). Links between climate, wetlands, and malaria in the Amazon Basin. *Journal of Emerging Infectious Diseases,* 15, 659-662. doi: 10.3201/eid1504.080822. Retrieved from http://www.cdc.gov/EID/content/15/4/659.htm

26. Pascual, M., Cazelles, B., Bouma, M. J., Chaves, L. F. & Koelle, K. (2008). Shifting patterns: Malaria dynamics and rainfall variability in an African highland. *Proceedings of the Royal Society B, 275,* 123-132. doi: 10.1098/rspb.2007.1068

27. Pascual, M., Ahumada, J., Chaves, L. F., Rodo, X., & Bouma, M. (2006). Malaria resurgence in East African highlands: temperature trends revisited. *Proceedings of the National Academy of Sciences of the USA, 103,* 5829-5834. doi:10.1073/pnas.0508929103.

28. Vittor, A. Y., Pan, W., Gilman, R. H., Tielsch, J., Glass, G. E., Shields, T., . . . Patz, J. A. (2009). Linking deforestation to malaria in the Amazon: Characterization of the breeding habitat of the principal malaria vector, Anopheles darlingi. *American Journal of Tropical Medicine and Hygiene, 89,* 5-12.

29. Ostfeld, S. R. & Keesing, F. (2000). Biodiversity and disease risk: The case of Lyme disease. *Conservation Biology, 14,* 722-728.

- **Human-induced genetic changes in disease vectors or pathogens**, such as mosquito resistance to pesticides or the emergence of antibiotic-resistant bacteria. The drivers of these changes include pesticide application and the overuse of antibiotics.
- **Environmental contamination by infectious disease agents**, such as fecal contamination of source waters. The drivers of such contamination include (1) lack of sanitation; (2) increased rainfall and runoff, often from impervious surfaces caused by urban sprawl or climate change-related extremes of the hydrologic cycle; and (3) deposition of chemical pollutants, including nutrients and fertilizers.

While maintaining undisturbed ecosystems can protect against emergence or spread of disease in some circumstances,[30] there are recognized trade-offs between sustaining this particular ecosystem service and making changes in ecosystems to achieve some other public good. Probably the best documented examples of such trade-offs involve water projects for agriculture, electrical power, or flood control. The pace of irrigation development has increased rapidly over the past half-century in response to increasing food requirements of human populations, but irrigation and dam construction can also increase transmission of diseases such as schistosomiasis, Japanese encephalitis, and malaria[31].

Existing Mechanisms and Institutional Frameworks

Decisions regarding trade and transportation can affect the introduction of disease organisms, their vectors, or both; the introduction or transport of livestock can affect ecosystems in destination areas, causing shifts in biodiversity that directly or indirectly affect human health; and human migrations can cause, or help to cause, changes in biodiversity and ecosystems. The National Invasive Species Council was established by Executive Order (E.O.) 13112 specifically to ensure that Federal programs and activities to prevent and control invasive species are coordinated, effective, and efficient. E.O. 13112 defines invasive species as "…an alien (or non-native) species whose introduction does, or is likely to cause economic or environmental harm or harm to human health."[32] Yet, interagency cooperation still needs to be strengthened, largely through appropriate informatics-based data sharing, to carry out the intent of E.O. 13112.

In the United States, Title I of the National Environmental Policy Act of 1970 (NEPA) contains a Declaration of National Environmental Policy, which requires the Federal government to "use all practicable means . . . to create and maintain conditions under which man and nature can exist in productive harmony."[33] Section 102 of NEPA requires Federal agencies "to utilize a systematic, interdisciplinary approach which

30. Patz, J. A., Daszak, P., Tabor, G. M., Aguirre, A. A., Pearl, M., Epstein, J., . . . Members of the Working Group on Land Use Change and Disease Emergence. (2004). Unhealthy landscapes: Policy recommendations on land use change and infectious disease emergence. *Environmental Health Perspectives, 101,* 1092-1098.

31. Patz, J.A., Confalonieri, U. E. C., Amerasinghe. F., Chua, K. B., Daszak, P., Hyatt, A. D., Molyneux, D., . . . Rubio-Palis, Y. (2005). Health: Ecosystem regulation of infectious diseases. In Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Current State and Trends. Findings of the Condition and Trends Working Group. Ecosystem Assessment Series.* Washington, DC: Island Press.

32. National Invasive Species Information Center (NISIC): *Gateway to invasive species information; covering Federal, State, local, and international sources.* http://www.invasivespeciesinfo.gov/

33. United States Environmental Protection Agency. (2008). *Full text of NEPA—National Environmental Protection Act of 1969, as amended,* Sec 101 [42 USC § 4331]. Retrieved from http://www.ehso.com/Laws_NEPA.htm

will insure the integrated use of the natural and social sciences . . . in planning and in decision-making".[34] Specifically, all Federal agencies are to prepare detailed Environmental Impact Statements (EIS) that report the environmental impact of and alternatives to major Federal actions that, if taken, will significantly affect the environment. Section 102 also requires Federal agencies to lend appropriate support to initiatives and programs that are designed to anticipate and prevent a decline in the quality of mankind's world environment. Federal government initiatives that cover some of this area are listed in Box II-1, although the focus needs to be broadened and made more integral to the activities of all agencies that deal with biodiversity and ecosystems, as well as the public health. Despite the clear inclusion of human health in NEPA, environmental impact statements rarely, if ever, contain thorough considerations of health impacts of changes in biodiversity or ecosystems.

Internationally, Agenda 21[35] and the *Rio Declaration on Environment and Development*[36] both describe a comprehensive approach to ecologically sustainable development that incorporates cross-sector policies, many of which are relevant to human health. These include:

- Integrated action for health, such as *health impact assessments* (HIA) of major development projects, policies, and programs, and indicators for health and sustainable development;
- Inclusion of health in sustainable development planning efforts, in multilateral trade and environmental agreements, and in poverty reduction strategies;
- Improvement of cross-sector collaboration between different tiers of government, government departments, and non-governmental organizations; and
- International capacity-building initiatives that assess health and environmental linkages and use the knowledge gained to create more effective national and regional policy responses to environmental threats.

While EISs sometimes mention discrete health issues, the relationship between biodiversity and ecosystem change and health has not typically been addressed in a systematic manner in the EIS process. This could be addressed by including requirements for a comprehensive HIA along with the EIS. The HIA would be expected to report trade-offs that might be created if certain policy choices are made, and include considerations of time scale. HIAs of the burden of disease attributable to climate change, for example, indicate that impacts are modest compared with other risk factors over the short time scales within which many political decisions are made (commonly five years). However, these impacts become considerably more significant over several decades. Therefore, health impact considerations are quite relevant for programs with long time-horizons, such as reconstruction of urban sewer systems or construction projects in potentially flood-prone areas.

34. United States Environmental Protection Agency. (2008). *Full text of NEPA—National Environmental Protection Act of 1969, as amended,* Sec 101 [42 USC § 4332]. Retrieved from http://www.ehso.com/Laws_NEPA.htm

35. United Nations Dept. of Economic and Social Affairs Office of Sustainable Development. (1992). *Agenda 21: The United Nations program of action from Rio.* Retrieved from http://www.un.org/esa/dsd/agenda21/

36. United Nations Conference on Environment and Development. (1992). *Rio declaration on environment and development.* Retrieved from http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm

BOX II-1: SOME CURRENT U.S. GOVERNMENT INITIATIVES

- **International Cooperative Biodiversity Groups (ICBG) program**—The NIH Fogarty International Center has been leading an interagency conservation and molecular discovery of biodiversity-based pharmaceuticals (and other uses) program since 1993. Five other Institutes at the NIH and four other agencies (NSF, USDA, NOAA, and DOE) all participate (http://www.fic.nih.gov/programs/research_grants/icbg). As a result of this program, there have been a few notable conservation successes and a lot of attention paid to access and benefit sharing issues.
- **Ecology of Infectious Diseases program**—The NSF and NIH (Fogarty International Center, National Institute of General Medical Sciences [NIGMS], National Institute of Environmental Health Sciences [NIEHS]) since 2003 have been funding research in the area of the ecology of infectious diseases.
- **National Institute of Environmental Health Sciences**—The NIEHS in the past has concentrated on toxicological issues, but recently has begun to incorporate research on the effects of climate change, mold-caused maladies, etc.
- **EPA's Biodiversity and Human Health Initiative**—Encompasses extramural and interagency science/science policy projects to understand mechanisms linking anthropogenic stressors, biodiversity, and infectious disease transmission. EPA also has established an Interdisciplinary "Community of Practice" on Biodiversity, Landscape Change, and Human Health—established between researchers and decision-makers in natural resources, public health, and land use planning to improve decision-making at the local level.
- **EPA's Ecological Research Program**—A new research direction on ecosystem services, which includes understanding the vital link between ecosystem service provision and human health and well-being (illness and disease, livelihood, homeland security, cultural preservation, spiritual fulfillment).
- **Science Exhibit on "Healthy Ecosystems, Healthy People"**—EPA and Smithsonian National Zoological Park (Fall 2010).
- **USAID sponsored project, "Payment for Environmental Services"**—http://www.oired.vt.edu/sanremcrsp/PES.php.

Tools and Methods for Assessing Ecosystem Change Effects on Human Health

Now that the linkage between ecosystem change and human disease has been demonstrated in many settings, scientists have a growing need for improvements in tools and methods to detect such links more comprehensively and to characterize them for the use of policy makers and others.

- **Analytical software** is needed to help improve understanding of the linkages between ecological change and the emergence or changes in patterns of infectious diseases. These tools should be able to combine time-series analyses, geographic information systems and other forms of spatial analyses that use digital mapping, analysis of satellite remotely sensed imagery, spatial statistics, and ecological niche modeling so that researchers can identify and mitigate disease emergences and other threats to human health.

- **Infrastructural tools**, such as the developments in informatics capabilities and capacities described in Chapter VIII, are extremely important to support the analyses just described. In addition, informatics capacities for the delivery and deployment of more "upstream" (and therefore anticipatory) health-relevant data from a broad range of key information sources (biodiversity, socio-economic, and medical/public-health) are needed to build a comprehensive picture of the ecological drivers of human disease.

Growing awareness of the confluence of human health and global environmental change provides the international community with a unique opportunity to develop collaborations not only among the nations participating in the Rio Conventions on Biological Diversity,[37] Climate Change,[38] and Desertification,[39] but also with key international organizations, including the World Health Organization, the United Nations Environment Programme, the United Nations Development Programme, and other U.N. agencies. Many of the environmental and ecological factors that affect human health—deforestation and land use change, water quality and quantity, ecosystem services—cut across more than one of the treaty domains and therefore demand an integrated approach for successful international policy development. IPBES (see Chapter IV) should make health a priority consideration as it undertakes international ecosystem assessments, and ensure that health issues are included in all of its information products.

Stronger collaborative ties will come about only when data and information can flow readily among agencies and between the government and other sectors of society. These data must also be open to analytical tools that can turn those data into information that can be applied to promote human well-being. However, the informatics research and engineering required to provide open data is non-trivial and it needs to be a focus in its own right to reach its potential in enhancing human health. In the past, the information management aspects of interagency and intergovernmental cooperation have received only lip service, and thus informatics has not yet succeeded in fulfilling its promise.

Recommendations

- **The NSTC should request that the National Academy of Sciences conduct an assessment of the relationship of biodiversity preservation and human health, as well as provide recommendations for how federal agencies could best coordinate their efforts to preserve both.**
  - Virtually every Federal agency has a role in reducing human vulnerability and in improving economic and ecological sustainability. Advice from the National Academies on how to leverage these mandates and quickly advance the twin goals of improving health and improving the quality of our ecosystems can inform strategic planning across the U.S. Government.
  - The study should provide options for the Federal government to integrate considerations of health and environment in research, planning, and management decisions.

37. Convention on Biological Diversity. Retrieved from http://www.cbd.int
38. United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/2860.php
39. United Nations Convention to Combat Desertification. Retrieved from http://www.unccd.int/

- **The President's Council on Environmental Quality (CEQ) should issue guidance for considering health effects of change in ecosystems and biodiversity in the NEPA process.**
  - The National Environmental Policy Act (NEPA) was formulated with the explicit purpose of protecting human health. The regulations on its implementation define health as one of the effects that must be considered in an EIS.
  - Guidance for developing assessments of the health impacts of biodiversity and ecosystem change occasioned by development already exists in the international arena.
- **EcoINFORMA, described in Chapter VIII, must have the authority to coordinate Federal agencies' data-sharing efforts and to collaborate internationally to develop standards for data and metadata that will support an international collaboration on environment-related health issues.**

III. Ecosystem Assessments for Predicting and Adapting to Change

For more than 40 years, Americans have supported laws and programs designed to protect the water, air, forests, and land of the United States, as well as the health of its citizens. Today, these laws and programs inform activities in almost every economic sphere and provide a basis for both Federal and local policies. They are so important that the Federal Government spends approximately $650 million yearly on ground-based monitoring of specific aspects of environmental conditions and processes (see Appendix A for an inventory of these programs). The data harvested by these exercises, though Federally held and used, also serve vital regional and local government needs and myriad private sector activities.

Despite the abundance of *data* that come from existing monitoring programs, decision makers at every level lack sufficient *information*—that is, the results of analysis and interpretation of data. This lack keeps decision makers from fully understanding causes of ecosystem change, even though ecosystems have been and are changing—in some cases dramatically—because of human activity and natural factors. And, ongoing climate change will increasingly rapidly, and unpredictably, affect the transformation of ecosystems. For decision-makers to improve policy and cost-effectively address adaptation to change, they need a better understanding of the causes, trends, and rate of changes in ecosystems and thus the services they provide.

The synthesizing process that integrates data from monitoring programs, other existing datasets, and research results is called *assessment*. Effective national, regional, and local assessments of biodiversity and ecosystem services are tools that are needed now to understand and anticipate environmental change. Without them, the sustainability of our environment, economy, and national heritage is jeopardized. In this chapter, we discuss the characteristics of the national ecological assessment that we recommend.

Previous and Existing National Assessments

Other countries have recently instituted (such as the United Kingdom[40] in 2010) such assessments, but the Congress of the United States recognized this need in 1970, when it passed the Environmental Protection Act. From 1970 to 1997, the Council on Environmental Quality (CEQ) provided yearly Environmental Quality Reports[41] as required by that Act. Recent U.S. efforts to address the need for ecological assessment include the *State of the Nation's Ecosystems* studies of 2002 and 2008, published by The H. John Heinz III Center for Science, Economics, and the Environment (hereafter referred to as the

40. Living with Environmental Change. (2010). *United Kingdom National Ecosystem Assessment*. Retrieved from http://www.lwec.org.uk/activities/nea

41. Council on Environmental Quality. *CEQ Proactive Disclosure Reading Room*. Retrieved from http://www.whitehouse.gov/administration/eop/ceq/foia/readingroom

Heinz Center).[42,43,44] These reports noted substantial gaps in the data available and called for a stronger Federal role in both data collection and assessment.

Under the Global Change Research Act of 1990, the next national assessment of global change impacts on the nation is due to Congress in 2013[45], and is being designed now. Although the Act calls for an assessment that "analyzes the effects of global change," the previous assessments (e.g. *The First U.S. National Assessment* [2000])[46] in this series primarily focused on climate change, without a thorough consideration of ecosystems. This appears to be the case for the one in progress as well, which is being called the National Climate Assessment (NCA) and which will incorporate components for climate services[47] and for adaptation.[48] The NCA would be significantly more useful if it were coupled with an assessment that synthesized information about biodiversity and ecosystem sustainability.

The United States has a number of ongoing efforts that touch on or could form part of a thorough national ecosystem assessment. For instance, the Environmental Protection Agency now issues periodic "Reports on the Environment,"[49] and there are a number of ongoing monitoring programs (Appendix A), as well as regular assessments of various aspects of the environment (Appendix B), including among a number of others the Forests Inventory and Analysis Program and the National Resources Inventory of the USDA, the National Water Quality Assessment of the USGS and other agencies, and the U.S. Fish and Wildlife Service's National Wetlands Inventory. None, however, are comprehensive. The Working Group believes that an overview approach is necessary to discover ramifications of variation across many factors at once.

Characteristics of a National Ecosystem Assessment

An ecosystem assessment that would be maximally useful would enable the Nation to track ongoing changes and to develop predictive scenarios of future change. Such an assessment would depend on sustained quantitative benchmarks for biodiversity status and distribution, water quality, soil fertility, and

---

42. The H. John Heinz III Center for Science, Economics, and the Environment. (2002, updated 2003, 2005). *The state of the nation's ecosystems: Measuring the land, waters, and living resources of the United States.* Retrieved from http://www.heinzctr.org/ecosystems/2002report/index.html

43. The H. John Heinz III Center for Science, Economics, and the Environment. (2005). *Filling the gaps: Priority data needs and key management challenges for national reporting on ecosystem condition*. Retrieved from http://www.heinzctr.org/Programs/Reporting/Working%20Groups/Data%20Gaps/Gaps_LongReport_LoRes.pdf

44. The H. John Heinz III Center for Science, Economics, and the Environment. (2008). *The state of the nation's ecosystems 2008: Measuring the land, waters, and living resources of the United States.* Island Press, Washington, D.C. ISBN: 9781597264716. Retrieved from http://www.heinzctr.org/ecosystems/2008report/pdf_files/Highlights_Final_low_res.pdf

45. Federal Register, Vol. 75, No. 172, Tuesday, September 7, 2010; http://regulations.justia.com/view/194875

46. United States Global Change Research Program. *First U.S. National Assessment (2000).* Retrieved from http://globalchange.gov/publications/reports/scientific-assessments/first-national-assessment

47. U.S. House of Representatives. (2009). *Testimony of John P. Holdren, Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy, Executive Office of the President of the United States, before The Select Committee on Energy Independence and Global Warming, U.S. House of Representatives on The Administration's View of the State of the Climate, December 2, 2009.* Retrieved from http://globalwarming.house.gov/tools/3q08materials/files/holdren.pdf

48. Council on Environmental Quality. *Evolving Components to Support a National Adaptation Strategy.* Retrieved from http://www.whitehouse.gov/administration/eop/ceq/initiatives/adaptation/evolving-components

49. The 2008 EPA ROE is presented in three parts: 1) the "printed" (PDF) document (http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=190806), 2) a shorter "highlights" document (http://oaspub.epa.gov/hd/downloads), and 3) an electronic version as a dynamic website (http://cfpub.epa.gov/eroe). The last will be updated as data become available. The former two will be attempted every four years; the next one is due in 2012. There is some regional detail in these.

many other critical ecological features. In its 2002 report,[50] the Heinz Center reported on the extensive series of scientific community workshops that had developed a list of 103 vital indicators (data types needed for a thorough assessment), only 32 of which existed at that time. Three years later, the Center released a separate report[51] in which it identified the ten highest-priority data types among the missing indicators, such as the areas of key habitats, the nitrogen loads in rivers, and carbon storage in plants and soils. Following this, a National Academy of Public Administration (NAPA) report[52] was published on how to set up a National System of Environmental Indicators.

A large number of agencies (see Table III-1) conduct programs that monitor and assess various aspects of the biological world. However, none is comprehensive. We recommend here that such a comprehensive assessment be conducted every four years, and that it could be called the Quadrennial EcoSystems Trends (QuEST) Assessment. Comprehensive assessments such as this can only be timely, balanced, and cost-effective if the Federal Government fundamentally upgrades the use of environmental informatics. The necessary upgrades, based on the existing Open Government Data initiative, are described in Chapter VIII.

The agencies in Table III-1 hold existing ecological datasets that would be useful in a thorough assessment. The assessment should also make use of programs of non-profit and non-governmental entities that cross-link Federal datasets, particularly those that collaborate with U.S. government agencies to provide nationally consistent biodiversity information. Many of these include valuable information about individual species and about the variation and abundance of species within and among ecosystems—that is, biodiversity. They also include data about ecosystem properties such as soils, minerals, climate, human activities, and other features.

The assessment process that analyzes and synthesizes all of these data should be carried out on a regular interval, and should provide information on and a review of

- Status and trends of biodiversity, ecosystems, and the services that they provide;
- Research on biodiversity and sustainability of ecosystems, and their interconnection with the economy;
- Consequences of change in these systems for human health and well-being (see Chapter II);
- Emerging challenges to ecosystem sustainability (e.g., greater demand on agriculture for both food and fuel production); and
- Possible remedies to emerging challenges to ecosystem sustainability.

---

50. The H. John Heinz III Center for Science, Economics, and the Environment. (2002, updated 2003, 2005). *The State of the Nation's Ecosystems 2008: Measuring the Land, Waters, and Living Resources of The United States.* Retrieved from: http://www.heinzctr.org/ecosystems/2002report/index.html

51. The H. John Heinz III Center for Science, Economics, and the Environment. (2005). *Filling the gaps: Priority data needs and key management challenges for national reporting on ecosystem condition.* Retrieved from http://www.heinzctr.org/Programs/Reporting/Working%20Groups/Data%20Gaps/Gaps_LongReport_LoRes.pdf

52. National Academy of Public Administration. (2007). *A green compass: Institutional options for developing a national system of environmental indicators.* Retrieved from http://www.napawash.org/publications-reports/a-green-compass-institutional-options-for-developing-a-national-system-of-environmental-indicators/

Table III-1. List of Federal agencies that hold existing ecological datasets that can support the Quadrennial Ecosystems Services Trends (QuEST) assessment. Datasets held by these agencies are not all available online, or if they are available, they are not presented in an interoperable manner that allows data integration (see Chapter VIII) with other Federal data sets or with data provided by other sectors of society.

Centers for Disease Control and Prevention	U.S. Department of Agriculture
U.S. Department of Commerce	Economic Research Service
Bureau of Economic Analysis	Office of Environmental Markets
Census Bureau	Farm Service Agency
National Oceanic and Atmospheric Administration	Forest Service
National Marine Fisheries Service	National Agricultural Statistics Service
National Ocean Service	Natural Resources Conservation Service
Satellite and Information Service	U.S. Department of the Interior
U.S. Department of Defense	U.S. Geological Survey
U.S. Army Corps of Engineers	U.S. Fish and Wildlife Service
Office of Naval Research	Bureau of Ocean Energy
Environmental Protection Agency	Bureau of Reclamation
Environmental Monitoring and Assessment Program	National Park Service
National Center for Environmental Economics	Office of Surface Mining
Office of Air and Radiation	Office of Natural Resource Restoration
National Air and Space Administration	Ocean, Coastal and Great Lakes Activities
Mission to Planet Earth	

The QuEST Assessment must be closely coordinated with the National Climate Assessment.[53] Two options for organizing QuEST are:

- The Committee on Environment and Natural Resources Sustainability (CENRS)[54] could be charged with the ongoing coordination of the QuEST Assessments. CENRS has subcommittees on Air Quality Research, Disaster Reduction, Ecological Systems, Global Change Research/Climate Change Science, Ocean Science & Technology, Toxics and Risks, U.S. Group on Earth Observations, and Water Availability & Quality. Alternatively, CENRS could charge its new Sustainability Task Force to coordinate the QuEST Assessments.
- An independent entity, such as the Heinz Center,[55] could be funded to provide ongoing QuEST Assessments. As noted above, the Heinz Center has developed a set of environmental indicators and has sought to report on them every few years.[56] The data from the Center's *State of the Nation's Ecosystems 2008* is archived at the Department of Interior, and the process could easily be revived. The Heinz Center is also well-placed to coordinate the public-private partnerships that are integral to the Assessment process.

53. United States Global Change Research Program. *National Climate Assessment.* Retrieved from: http://www.globalchange.gov/component/content/article/67-themes/154-spotlight1

54. Office of Science and Technology Policy. *NSTC Committee on Environment, Natural Resources, and Sustainability.* Retrieved from http://www.whitehouse.gov/administration/eop/ostp/nstc/committees/cenr

55. The H. John Heinz III Center for Science, Economics and the Environment. Retrieved from http://www.heinzctr.org/

56. Guldin, R.W. *National Environmental Status and Trends (NEST) Indicator Project.* Retrieved from http://acwi.gov/monitoring/ppt/ftcollins_072208/NEST_22July2008.pdf

A national assessment can draw on (and feed back to) regional assessments such as that for the Gulf of Mexico (see Box III-1), which have the advantage of being driven by local stakeholders and state governments, while at the same time addressing issues of national importance, such as common needs for clean water and flood control. Current regional assessments being performed under Federal auspices include the NOAA Regional Integrated Sciences and Assessments (RISAs); the regional climate impacts assessments conducted as part of the National Climate Assessment; and the new agency regional centers, such as the DOI's National Climate Change and Wildlife Science Centers, the National Ecological Observatory Network (NEON), and the Long-Term Ecological Research (LTER) sites funded by NSF. Coordination between Federal and non-Federal efforts will be essential. The members of the Working Group recommend Federal funding for pilot projects that demonstrate effective partnerships and approaches. As assessment activities grow more numerous, a relatively small investment in exemplary pilots could bring large returns.

The usefulness of regional efforts, however, will depend on shared standards and protocols, for both the science and the resulting data, in order to translate regional datasets into meaningful national data and vice-versa. Because climate change is already altering such environmental features as the historic ranges of species and ecosystems, national assessment results would also inform regions and provide a common forum for localities, states, and regions to discuss localized changes that may have national implications. Integrated regional assessments are relatively new, though of great value, to local decision makers and communities (for example, the Gulf of Mexico region, see Box III-1). A clearinghouse of best practices on data gathering and informatics architectures for regional ecosystems would be extremely useful to future studies of such complex areas.

Recommendations

- **Establish, by Executive Order, a regular and ongoing Quadrennial EcoSystems Trends (QuEST) Assessment that spans national, regional, and local scales in order to provide improved information for environmental and economic policy decisions.**
  - The QuEST Assessment should be coordinated with the Global Change Assessments mandated by the Global Change Research Act of 1990 (P.L. 101-606).
- **The Office of Management and Budget (OMB) should enforce, for biodiversity and ecosystem services data, the Open Government requirement that data be made freely available to all stakeholders through the use of open, machine-readable data storage systems as rapidly as possible.**
  - Recommendations in Chapter VIII regarding coordination of standards for data, data integration, and data interoperability by EcoINFORMA are of essential importance in conducting the QuEST Assessment envisioned here.
- **As part of its environmental informatics activities, EcoINFORMA (recommended in Chapter VIII) should be given the authority to gather and integrate a compendium of best practices from regional integrated assessments that will mutually inform the QuEST Assessment as well as regional assessments.**

BOX III-1: REGIONAL ECOSYSTEM ASSESSMENT FOR THE GULF OF MEXICO

The Gulf of Mexico has enormous environmental and economic value for our Nation. It teems with sea life. Its coastal region contains half the coastal wetlands in the United States and is home to valuable and abundant wildlife. The Gulf region's ecological communities sustain economic and recreational industries of national importance.

Yet the story of the Gulf is also a story of disruption and degradation. Hurricanes are a fact of life along the coast; Hurricane Katrina in 2005 created devastation that is yet to heal. The Deepwater Horizon oil blowout of 2010 posed an unprecedented emergency for the marine environment and coastal ecosystems and industries. Pollution and sediment from many sources enters the Gulf from thousands of miles away by way of the Mississippi and other rivers.

Understanding ecosystem change in this system—let alone planning for it—is a very big challenge. For example, reducing the large hypoxic zones in Gulf waters, which are harmful to fisheries and many other species, requires sustained change in farming practices and nutrient usage far to the north.

One tool that is proving useful in addressing this barrage of challenges to the Gulf of Mexico is a regional assessment that incorporates data from diverse sources about ecosystem services and status. This assessment entails Federal and state partnerships, community stakeholder engagement, and—crucially—solid science. It is also a crucial tool in efforts to enhance the economic and ecological health and sustainability of the region.

The Gulf of Mexico Alliance was formed in 2004 to assess and balance the competing demands on the Gulf with the aim of contributing to smarter resource use and improved public-policy decisions. The vision of the Alliance is that if the economic values of Gulf ecosystems are inventoried and documented, then the economic values of ecosystem services can be incorporated into coastal-resource-management decisions. The Alliance engages five states (Florida, Alabama, Mississippi, Louisiana, and Texas) and Federal and international agencies, as well as business, industry, and nonprofit organizations.

This regional effort has produced Governors' Action Plans that focus on water quality, coastal resilience, nutrient pollution and its impact, environmental education, and habitat restoration.

The practical value of regional assessments is clear and compelling. For example, in Figure 1 the digital elevation data, habitat maps, and storm frequency models have been combined to produce a coastal vulnerability index that enables prediction of changes expected from sea level rise as the Earth warms.

Figure 1. Map of the Coastal Vulnerability Index (C.V.I.) for the U.S. Gulf Coast. The C.V.I. shows the relative vulnerability of the coast to changes due to future rise in sea level. Areas along the coast are assigned a ranking from low to very high risk, based on the analysis of physical variables that contribute to coastal change.

Regional assessments are important not just for planning, but also for providing benchmarks against which damages such as those from the Deepwater Horizon oil blowout can be estimated. As an example, in Figure 2, maps of the oil slick have been overlaid with maps of primary productivity.

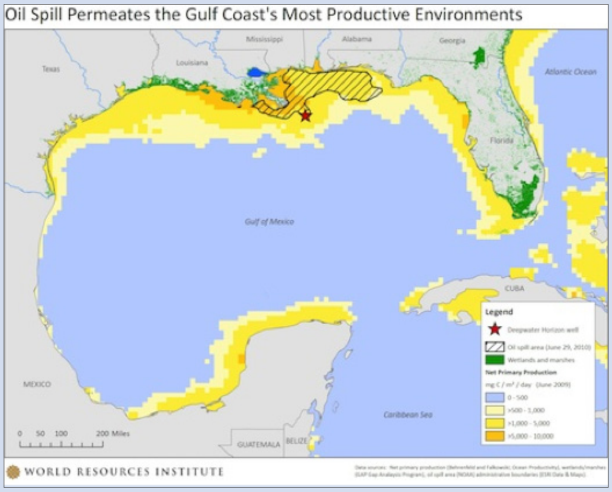

Figure 2. The Deepwater Horizon oil spill affected the Gulf coast's areas of greatest primary productivity. In the Gulf, primary productivity—measured in milligrams of carbon fixed per square meter per day–ranges from near zero to 7,300 near the Mississippi Delta at its peak in June and July. The Deepwater Horizon oil spill reached the Gulf's area of highest primary productivity at the time of its yearly maximum. Recent research indicates that each 1% increase in primary productivity corresponds to a 1.3% increase in the fishery catch. Regional assessments make these sorts of linkages and insights possible.

The regional assessments produced by the Gulf of Mexico Alliance have been used to steer Federal funding for habitat restoration toward areas that will yield the greatest public benefit. NOAA, for example, using data on critical habitats and the ecosystem services those habitats provide, has applied $4 million toward the restoration of the Grand Isle and Saint Barnard marshes in Louisiana (accounting for 57 jobs and 3.4 miles of shoreline) and $2.9 million toward the restoration of Coffee Island in Alabama (49 jobs and 1.4 miles of shoreline).

Prior to the Deepwater Horizon oil blowout, NOAA invested $9.2 million in the Gulf for habitat restoration. Today, much larger investments in restoration are required. Future plans by all stakeholders now can be based on the regional assessment and appropriately balance the oil industry's needs against valuable ecosystem services. As a result, private funds, Federal funds, and reparation funds from British Petroleum (BP) will be better spent.

Sources

National Ocean Service, NOAA. (2008). *Gulf of Mexico at a glance.* Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Retrieved from http://gulfofmexicoalliance.org/pdfs/gulf_glance_1008.pdf

Thieler, R. E. & Hammar-Klose, E. S. (2006). *National assessment of coastal vulnerability to sea-level rise: Preliminary results for the U.S. Gulf of Mexico coast* (U.S. Geological Survey Open-File Report 00-179). Retrieved from http://pubs.usgs.gov/of/2000/of00-179/

The Nature Conservancy. (2010). *Investing in nature: Creating jobs and restoring coastal habitat.* Retrieved from http://www.habitat.noaa.gov/pdf/tnc_noaa_arra_restoration_summary.pdf

Gulf of Mexico Alliance. (2010). Retrieved from http://gulfofmexicoalliance.org

IHS Global Insight. (2010). *The economic impact of the Gulf of Mexico offshore oil and natural gas industry and the role of the independents.* Retrieved from http://www.rpsea.org/en/art/294/

IV. International Aspects of Assessments

Globalization—the closer integration of the world economy—and circulation within the atmosphere and hydrosphere mean that local land use changes potentially affect people everywhere. The weight of scientific evidence, reported in global assessments of change in both the atmosphere and the biosphere, confirms that the destabilizing effect of anthropogenic environmental change poses serious threats to human well-being worldwide.[57,58]

The activities of the 6.9 billion people on the planet are transforming the biosphere in ways that affect ecosystem services at multiple scales. Some activities involve consequences that are realized primarily locally, such as on the effect of land clearance on water quality and quantity in local catchments, or the effect of pesticide use on crop pollinators. Others involve regional or global benefits or costs, such as of the effect of local conservation of endangered species on the information contained in the global gene pool, or the effect of local land use and trade on emerging diseases (see Chapter II).

Management of resources beyond national jurisdiction and the regulation of the international impacts of local activity both depend on international cooperation. Increasingly, the same is true of the science of biosphere change. Our existing knowledge provides a basis for many actions needed to manage specific aspects of global environmental change, but is not sufficient to support fully integrated solutions. Societies urgently need the knowledge-base that will allow them to meet their development goals, while at the same time reducing environmental risk. A coordinated international global change research effort, building upon and informing the strong global-change research currently conducted in the United States, can help address a number of the challenges embedded in the international community's eight Millennium Development Goals,[59] which include, among others, (a) ensuring environmental sustainability, (b) improving human health and security, and (c) eradicating extreme poverty and hunger.

In this chapter, we identify several international initiatives that amass and make ecological and ecosystem data available and accessible, perform assessments on those data and others in service to better adaptation to ecological change, and conduct research that will contribute to the store of knowledge about ecosystem function and its response to anthropogenic and other stressors. In particular, we call out the newly established Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and recommend that the United States play a leadership role in its development to ensure that the organization realizes its potential, and utilizes the power of informatics to generate assessments. Global observing and informatics systems such as the Biodiversity Observation Network of the Group on Earth Observations (GEO BON) and the Global Biodiversity Information Facility (GBIF), as well as a revitalized global change research program, are required to supply IPBES with data and information. Our recommendations are aimed at strengthening all these capacities.

---

57. Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: General Synthesis.* Washington, DC: Island Press

58. Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: Synthesis report*. Geneva: IPCC. Retrieved from http://www.preventionweb.net/files/2335_ar4syr.pdf

59. United Nations Millennium Development Goals. *Background.* Retrieved from http://www.un.org/millenniumgoals/bkgd.shtml

Existing International Initiatives

A number of initiatives to enhance monitoring and assessment of biosphere change at a global scale are either in preparation or already underway. Three categories of these are especially important for the science of biodiversity and ecosystem services:

Observation systems. These include the Group on Earth Observations (GEO), the Group on Earth Observations Biodiversity Observation Network (GEO BON),[60] the Global Ocean Observing System (GOOS),[61] and the Global Biodiversity Information Facility (GBIF).[62] GEO is a partnership of 70+ member countries and 50+ organizations mandated to improve coordination of existing earth observations, implement new observations, and promote development of Earth-observation products. It oversees a Global Earth Observation System of Systems (GEOSS). GEO BON[63] is one of the first GEOSS systems proposed. GOOS[64] is a system of programs designed to establish an operational ocean-observation capability. It aims to monitor, understand, and predict changes in the state of the ocean, including living resources, and to enable ocean research. GOOS is sponsored by UNESCO through the Intergovernmental Oceanographic Commission (IOC), as well as by the UN Environment Program (UNEP), the World Metrological Organization (WMO), and the International Council of Science (ICSU). Within the United States, the Integrated Ocean Observing System (IOOS)[65] coordinates the U.S. contribution to GOOS. The biological components of these observing systems, as well as the data integration standards that they use and need to develop, are supported by the work of the Global Biodiversity Information Facility (GBIF). The GBIF is an international organization supported (as of Feb. 2011) by 32 countries and comprises an additional 23 countries as well as 46 international organizations[66] that work together to develop global community standards for data and metadata and to share data on biodiversity.

Assessment mechanisms. Current international assessments include the Millennium Ecosystem Assessment Follow-up[67] and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[68] that is now in development. The latter was effectively approved by the United Nations General Assembly in December 2010 through a resolution that invites UNEP to host an intergovernmental conference to "determine modalities and institutional arrangements" of the new body. Functions of IPBES will include (a) identifying and prioritizing key scientific information needed for policymakers at appropriate scales, (b) performing regular and timely assessments of knowledge on biodiversity and ecosystem services and their inter-linkages, which should include comprehensive

60. Scholes, R. J., Mace, G. M., Turner, W., Geller, G. N., Jürgens, N., Larigauderie, A., . . . Mooney, H. A. (2008). Toward a global biodiversity observing system. *Science, 321*, 1044-1045. doi:10.1126/science.1162055

61. Glenn, S. M., Dickey, T. D., Parker, B., & Boicourt, W. (2000). Long-term, real-time coastal ocean observation networks. *Oceanography, 13,* 24-34. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.132.686&rep=rep1&type=pdf

62. Edwards, J. L., Lane, M. A., & Nielsen, E. S. (2000). Interoperability of biodiversity databases: Biodiversity information on every desktop. *Science, 289,* 2312-2314. doi: 10.1126/science.289.5488.2312

63. Group on Earth Observations. (2008). *GEO BON concept document*. Retrieved from http://www.earthobservations.org/documents/cop/bi_geobon/200811_geobon_concept_document.pdf

64. Global Ocean Observing System. Retrieved from http://www.ioc-goos.org/

65. Integrated Ocean Observing System. Retrieved from http://www.ioos.gov/

66. Global Biodiversity Information Facility, *Governing Board*. Retrieved from http://www.gbif.org/governance/governing-board

67. Convention on Biological Diversity. (2008). *The Millennium Ecosystem Assessment (MA) follow-up–A global strategy for turning knowledge into action.* Retrieved from http://www.unep-wcmc.org/EAP/MA-Follow-up-strategy.aspx

68. Mooney, H., & Mace, G. (2009). Biodiversity policy challenges. *Science, 325,* 1474. doi:10.1126/science.1180935

global, regional, and, as necessary, sub-regional assessments and thematic issues at appropriate scales and new topics identified by science, (c) supporting policy formulation and implementation, and (d) prioritizing key capacity-building needs to improve the science-policy interface.[69,70] Relative to other major assessments, IPBES should provide more direct support to policy makers at many levels. IPBES assessments should provide conditional predictions of the consequences of specific policy options at well defined spatial and temporal scales.[71]

There are a large number of other international environmental assessments that are relevant to biodiversity and ecosystem services. These include the Dryland Land Degradation Assessment (FAO); the Forest Resources Assessment (FAO); the State of the World's Plant Genetic Resources (FAO); State of the World's Animal Genetic Resources (FAO); the Global International Waters Assessment (UNEP); the Global Environment Outlook (UNEP); the Intergovernmental Panel on Climate Change (IPCC); the World Resources Report (WRI); the World Water Assessment (UNESCO); the State of the World's Traditional Knowledge on Biodiversity (CBD); and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD).[72] However, it is likely that IPBES will become the body primarily responsible for assessing the relation between biodiversity change and the benefits that people get from ecosystems.

Global change research programs. International programs of global change research include DIVERSITAS, the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program (IHDP), and the World Climate Research Program on Global Environmental Change (WCRP), together with international research institutes partly funded by the United States, such as the International Institute for Applied Systems Analysis (IIASA) . These global change research programs are sponsored by the International Council for Science (ICSU) and are supported by national governments through both direct subscription and their research funding organizations. They are loosely linked through the Earth Systems Science Partnership.[73]

When the global-change research programs listed above were established, they represented a revolutionary response by the scientific community to the need to coordinate research across countries and continents to understand the functioning of the Earth system as a whole. These programs were designed when the bulk of global-change research involved the natural sciences; however, understanding the Earth system requires the involvement of the full range of sciences and humanities. In addition, the research agendas of past and ongoing programs were designed without the active engagement of potential 'users' of the knowledge generated. These programs have been generally successful, but given their current structure and focus, they are not well aligned with the broader research needs now

69. Larigauderie, A., & Mooney, H. (2010). The intergovernmental science-policy platform on biodiversity and ecosystem services: moving a step closer to an IPCC-like mechanism for biodiversity. *Current Opinion in Environmental Sustainability,* 2, 9-14. doi:10.1016/j.cosust.2010.02.006

70. United Nations Environment Programme. *Busan outcome.* Retrieved from http://www.unep.org/pdf/SMT_Agenda_Item_5-Busan_Outcome.pdf.

71. Perrings, C., Duraiappah, A., Larigauderie, A., & Mooney, H. (2011). The biodiversity and ecosystem services science-policy interface. *Science, 331.* 1139-1140. doi: 10.1126/science.1202400

72. Clark, W. C., Mitchell, R. B. & Cash, D. W. (2006) Evaluating the Influence of Global Environmental Assessments. *Global Environmental Assessments: Information and Influence* (ed. by R.B. Mitchell & W.C. Clark & D.W. Cash & N.M. Dickson), pp 1-28. Boston, MA: MIT Press

73. International Council for Science. (2010). *Earth system science for global sustainability: Grand challenges.* Retrieved from http://www.icsu-visioning.org/other/grand-challenges/

facing society.[74,75] Today, priorities are shaped by an urgent need for both trans-disciplinary science and the active involvement of potential users of research results. In addition to the efforts to understand the functioning of the Earth system and to examine human impacts on that system, there is a need to understand the consequences of global change for societies and to understand how to effectively mitigate those consequences and adapt to that change.[76]

In short, it is time for reform of the structure and focus of international global change research. The International Council for Science (ICSU), in consultation with researchers, 'users,' and funders, has recently developed a new agenda for global change research called *Grand Challenges in Earth System Science for Global Sustainability.*[77] This agenda provides an opportunity for fundamental restructuring and strengthening of the global-change research community that could mobilize the scientific community around the questions in this domain that most urgently confront society today. Given its leadership in global-change research, the United States can play a leading role in guiding the evolution of this approach.

International Information Challenges

The ability of the international research, observation, and assessment programs to deliver policy-relevant information awaits development of several informatics capabilities (see Chapter VIII). One of these is the ability to integrate and make interoperable the datasets required to inform policy, [78,79,80] and the software tools to make possible the modeling of complex systems sufficiently well to support prediction and the development of adaptation and mitigation strategies.[81, 82, 83] A third is the capacity of the scientific communities in developing countries to help fill gaps in data around the world, and to use informatics to undertake both research and assessment.[84,85]

74. Reid, W. V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y. T., Mokhele, K., . . . Whyte, A. (2010). Earth system science for sustainability: Global challenges. *Science, 330,* 916-917. doi: 10.1126/science.1196263

75. Ibid., National Research Council. (2009). *Restructuring Federal climate research to meet the challenges of climate change.* Retrieved from http://www.nap.edu/catalog.php?record_id=12595

76. Reid, W. V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y. T., Mokhele, K., . . . Whyte, A. (2010). Earth system science for sustainability: Global challenges. *Science 330,* 916-917. doi: 10.1126/science.1196263

77. Ibid., National Research Council. (2009). *Restructuring Federal climate research to meet the challenges of climate change.* Retrieved from http://www.nap.edu/catalog.php?record_id=12595

78. Scholes, R. J., Mace, G. M., Turner, W., Geller, G. N., Jürgens, N., Larigauderie, A., . . . Mooney, H. A. (2008). Toward a global biodiversity observing system. *Science, 321,* 1044-1045. doi:10.1126/science.1162055

79. Canhos, V. P., Souza, S., Giovanni, R., Canhos, D. A. L. (2004).Global biodiversity informatics: setting the scene for a 'new world' of ecological modeling. *Biodiversity Informatics, 1,* 1. Retrieved from https://journals.ku.edu/index.php/jbi/article/viewFile/3/1

80. Edwards, J. L., Lane, M. A., & Nielsen, E. S. (2000). Interoperability of biodiversity databases: Biodiversity information on every desktop. *Science, 289,* 2312-2314. doi: 10.1126/science.289.5488.2312

81. Perrings, C. (2007). Future challenges. *Proceedings of the National Academy of Sciences, 104,* 15179-15180. Retrieved from http://www.pnas.org/content/104/39/15179.full

82. Vespignani, A. (2009). Predicting the behavior of techno-social systems. *Science, 325,* 425-428. doi: 10.1126/science.1171990

83. Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., . . .DeAngelis, D. L. (2005).Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science, 310,* 987–991. doi: 10.1126/science.1116681

84. Blackmore, S. (1996). Knowing the Earth's biodiversity: Challenges for the infrastructure of systematic biology. *Science, 274,* 63- 64. doi:10.1126/science.274.5284.6

85. Geeta, R., Levy, A., Hoch, J. M., & Mark, M. (2004).Taxonomists and the CBD. *Science. 305,* 1105-1106. doi:10.1126/science.305.5687.1105

Integrating information from multiple sources. Disciplinary or system-based divisions have led to differences in research, monitoring, and assessment protocols that make both model and data integration problematic.[86,87] At the same time, the distribution of responsibilities among agencies, organizations, and multilateral agreements also ties bodies to particular sources of information and types of knowledge. Human health, agriculture, forestry, fisheries, and national parks, for example, are highly interdependent sectors that have evolved separate research, monitoring, and assessment systems to accompany separate administrative and governance structures. There have been significant strides in integrating distinct datasets within each area, but now there is a pressing need to develop the capacity to integrate data across these distinct but interconnected components of the system, generate information from those data, and to provide that information to an array of decision makers in usable form.[88]

Integration of space-based Earth observations and ground-based social observations. Space-based earth observation is the cornerstone of the earth observation systems, but it is poorly integrated with ground-based social, economic, and environmental data gathering. Integrating space-based Earth observation and ground-based ecological and social observations is needed to accurately predict anthropogenic environmental change.[89] Challenges to data integration are presented by difficulties in achieving interoperability across platforms, among countries and languages, and by conceptual and design issues. However, it is possible to address these challenges with existing and emerging informatics technologies (see Chapter VIII), many of which are being developed in the United States.

Generation and dissemination of information on global biosphere change. The clear need for applicable global information on biosphere changes has led to the international commitment to IPBES, which would provide information on status and trends in biodiversity and ecosystem services. *The Millennium Ecosystem Assessment*[90] demonstrated how uneven current knowledge is across countries, systems, and disciplines. It also showed us how weak is our capacity to economically value ecosystem services and thereby to project the environmental consequences of alternative economic and policy strategies.[91] *The Economics of Ecosystems and Biodiversity* (TEEB) project[92] is a major attempt to improve estimates of the value of changes in ecosystem services, but it also has revealed the unevenness of current knowledge. It is critical to establish IPBES on a sufficiently robust footing to provide reliable assessments of changes in the state of ecosystems, along with the causes, consequences, and economic costs of those changes.

86. Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., . . . Taylor, W. W. (2007). Complexity of coupled human and natural systems. *Science, 317,* 1513-1516. doi:10.1126/science.1144004

87. Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., . . . Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences, 106,* 1305-1312. Retrieved from http://www.pnas.org/content/106/5/1305.full

88. Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., . . . Patterson, C. (2009). Managing the health effects of climate change. *Lancet, 373 (9676),* 1693–1733.

89. Scholes, R. J., Mace, G. M., Turner, W., Geller, G. N., Jürgens, N., Larigauderie, A., . . . Mooney, H. A. (2008). Toward a global biodiversity observing system. *Science, 321,* 1044-1045. doi:10.1126/science.1162055.

90. Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: General synthesis.* Washington, DC: Island Press

91. Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., . . . Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences, 106,* 1305-1312. Retrieved from http://www.pnas.org/content/106/5/1305.full

92. The Economics of Ecosystems and Biodiversity. (2010). *The Economics of Ecosystems and Biodiversity.* Retrieved from http://www.teebweb.org/. TEEB. (2009). *Climate Issues Update.* Retrieved from http://www.teebweb.org/LinkClick.aspx?fileticket=L6XLPaoaZv8%3d&tabid=1278&language=en-US

Recommendations

- **Under the leadership of the State Department, and in coordination with the Office of Science and Technology Policy, the U.S. Government should support development of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to offer regular, thematic assessments of ecosystem change, as well as preliminary assessments of emerging issues.**
  - The Department of State, the U.S. Agency for International Development (USAID), and the Offices of Management and Budget (OMB) and Science and Technology Policy (OSTP) should identify funding sources to support global, international regional, and thematic ecosystem assessments and to support preliminary assessment of emerging issues.
  - If distinct assessment types are not separate line items in the IPBES budget, the United States should consider linking the funds it makes available to specific assessment types.
  - USAID should identify steps to build both the scientific and institutional capacity to undertake assessments of biodiversity and ecosystem services in developing countries.
- **The informatics-facilitating entity recommended below should be empowered to engage with GEO BON, GOOS, and GBIF to implement informatics developments that will integrate ground-based, spatially explicit observation of socio-economic causes and consequences of biosphere change with space-based observations that will contribute to the work of IPBES.**
  - The informatics facilitating entity (EcoINFORMA) recommended below (see Chapter VIII) should engage with the Ecosystem Service working group of GEO BON to ensure adoption of effective protocols for the integration of both earth and ground-based (biological, ecological, economic, and social) observations that are essential to the analysis and prediction of biosphere change.
- **Under the leadership of the Office of Science and Technology Policy, the U.S. government should work with the International Council for Science (ICSU) and other partners to refocus international global change research to address the Grand Challenges in Earth System Science for Global Sustainability that have been identified by ICSU, its partners, and the scientific community.**[93]
  - The United States should continue to support and provide data and expertise to GEO and its GEO BON, GOOS, and GBIF, among other initiatives.
  - It is important to establish beneficial feedback loops among these international initiatives and the QuEST Assessment (see Chapter III) and other national activities. This is most easily accomplished through the adoption of common information standards and protocols; as described in Chapter VIII, EcoINFORMA will be essential to achieve this.

---

93. Reid, W. V., Chen, D., Goldfarb, L., Hackmann, H., Lee, Y. T., Mokhele, K., . . . Whyte, A. (2010). Earth system science for sustainability: Global challenges. *Science, 330,* 916-917. doi: 10.1126/science.1196263.

V. Increasing the Effectiveness of Conservation Investments

Much can be accomplished with the knowledge in hand and the budgets already allocated for conservation purposes. In this time of economic stress and budget shortfalls, a central objective of this report is to advise the Government on how the funds it currently spends in support of biodiversity preservation and ecosystem sustainability can be stretched further to yield maximum benefit. One step toward this objective is to target conservation investments at the places and practices that have the potential for the largest improvements per dollar spent.

Federal agencies currently spend more than $10 billion annually on restoration activities, land or easement purchases, and incentive payments that have the primary goal of conserving biodiversity or protecting or restoring ecosystem services. These yearly conservation investments include nearly $6 billion spent on conservation under the Farm Bill to improve water quality, reduce soil erosion, and protect wildlife habitat; $3.8 billion in mitigation costs under major Federal regulatory programs;[94] nearly $1 billion annually for endangered species recovery;[95] and up to $900 million under the Land and Water Conservation Fund for the acquisition of land and water and conservation easements (although this has been funded at less than $200 million annually in recent years). These investments are of the same order of magnitude as recurring expenditures for core resource-management activities on Federal lands; for example, the budgets for the U.S. Forest Service (USFS) and the Bureau of Land Management (BLM) in 2010 were $5.3 billion and $1.03 billion respectively,[96,97] and the Fish and Wildlife Service spends $500 million annually on the National Wildlife Refuge system.[98, 99,100]

The reach of current Federal programs for conservation extends across terrestrial, aquatic, and marine ecosystem types and across both public and private domains. However, the investment being made is not yet successfully halting the net trend of ecosystem decline, although there may be local successes. Federal agencies could significantly increase the positive impact of conservation expenditures by giving highest priority to those expenditures that maximize the conservation benefits gained for each dollar invested.

---

94. Environmental Law Institute. (2007). *Mitigation of impacts to fish and wildlife habitat: Estimating costs and identifying opportunities.* Retrieved from http://www.elistore.org/Data/products/d17_16.pdf

95. Fish and Wildlife Service. (2008). *Federal and state endangered and threatened species expenditures.* Retrieved from http://www.fws.gov/endangered/esa-library/pdf/2008EXP.FINAL.pdf

96. U.S. Forest Service. *Budget.* Retrieved from http://www.fs.fed.us/aboutus/budget/

97. U.S. Department of the Interior. (2010). *President Proposes $1.1 Billion for BLM in Fiscal Year 2011 To Protect Resources and Manage Uses of Public Lands.* Retrieved from http://www.blm.gov/id/st/en/info/newsroom/2010/february/president_proposes.html

98. Fish and Wildlife Service. (2008). *Federal and state endangered and threatened species expenditures.* Retrieved from http://www.fws.gov/endangered/esa-library/pdf/2008EXP.FINAL.pdf

99. Fish and Wildlife Service. (2009). *FY 2010 Budget Justification.* Retrieved from http://www.fws.gov/budget/2010/2010%20Greenbook/03.%20Budget%20At%20A%20Glance%202010.pdf

100. Additional amounts are spent internationally by the Department of State (Oceans, Environment and Science), USAID (forests and biodiversity), the U.S. Forest Service (International Forest Programs), NOAA (Coral Reef Conservation Program), and the Department of Treasury (e.g. on the Tropical Forest Conservation Act). The Working Group is concerned with ecosystems and ecosystem change on the Nation's lands, wetlands and watersheds, so this chapter focuses on the major domestic conservation programs.

In this chapter, we first discuss how most Federal conservation funding is allocated by factors other than cost effectiveness (see Box V-1), and provide examples of greater cost-effectiveness in expenditures of conservation funds (see Box V-2). We then describe why greater use of cost-effectiveness analysis, combined with measures of Program Effectiveness (PE) could significantly improve conservation outcomes. Doing this would build on current policy that requires Return on Investment (ROI) assessments for Federal programs. We recommend that these methodologies be adopted by more agencies and programs so that taxpayer dollars can be used more effectively. And, in cases where agencies are not at liberty to make the most efficient allocation of resources, we recommend more transparency regarding opportunity costs to improve decision-making over the long term. Conservation investments do make a difference,[101] but we estimate that the cost-effectiveness of Federal ones could be increased by as much as a factor of two to ten, through prioritizing expenditures according to their cost-effectiveness (see Box V-2 and Figure V-1).

Current Conservation Programs Yield Uncertain Returns

One of the largest conservation investments by the Federal Government is payments for conservation practices by agricultural producers on cropland and ranchland. Though the Farm Bill authorizes dozens of such programs, we consider here the conservation returns (to the extent they are known) of two of the major ones. We also describe targeted programs that are yielding better returns. While the goals of these programs are determined by legislation, the oversight agency—USDA—should both track and report their net Program Effectiveness (PE).

The **Conservation Reserve Program** (CRP) had 33 million acres enrolled when the Farm Bill passed in 2008; it was authorized at $1.8 billion in FY2011. The CRP pays farmers to take their land out of crop production for a fixed period of time (10 to 15 years) and plant conservation cover, such as grasses and trees. The original "general enrollment" of CRP focused on preventing erosion and used an *Erodibility Index* based on the *universal soil loss equation*. Later, an *Environmental Benefits Index* (EBI) was developed that integrates goals such as wildlife food and shelter, pollinators, erosion avoidance, and air quality with the likely duration of the change undertaken.[102]

As an example, the payments to farmers to conduct some conservation practice might be evaluated in terms of pounds of nitrogen (N) runoff avoided per dollar spent. However, if the program has goals for ecosystem services other than water quality, such as wildlife habitat, then the positive impact on wildlife habitat of the action should be included in the cost effectiveness analysis. While this could be achieved using some 'weighting' of the physical measurements, the more rigorous approach would be to sum the economic benefit of the improved water quality and the economic benefit of improved wildlife habitat.

---

101. Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P. W., Fernandez-Manjarrés, J. F., . . . Walpole, M. (2010). Scenarios for global biodiversity in the 21st century. *Science, 330,* 1496—1501. doi: 10.1126/science.1196624

102. National Sustainable Agriculture Coalition. *Conservation Reserve Program.* Retrieved from http://sustainableagriculture.net/publications/grassrootsguide/conservation-environment/conservation-reserve-program/

BOX V-1: COST-EFFECTIVENESS

In this Report, we are defining the "effectiveness" measured in a cost-effectiveness analysis to be the progress achieved toward the conservation objectives of the program. The effectiveness of Farm Bill conservation investments would be the extent to which they reduce water pollution and soil erosion, and protect wildlife habitat. Depending on the goals of the conservation program, the effectiveness could be calculated in either environmental units (e.g., acres of high-biodiversity-value land) or in economic units (avoided damage costs associated with the economic value of the ecosystem services).

Because most conservation programs are designed to pursue multiple goals related to biodiversity and ecosystem services (and often social goals as well), calculating the effectiveness of programs aimed at multiple goals requires the use of a common metric of the economic value of the benefit achieved. This provides a more rigorous way to look at the effectiveness and costs of different conservation investments, where the effectiveness is measured in terms of the time-dependent increase in valuation of the ecosystem service or intended conservation goal (e.g., air quality, water quality, and biodiversity conservation). In some cases, it may not be possible to express some benefits of conservation investments in economic terms (e.g., reducing the threat to an endangered species) and it may be necessary to use an index that subjectively assigns weightings to the importance of progress toward goals that cannot be expressed in economic terms.

For a variety of reasons, agencies currently do not make adequate use of cost-effectiveness considerations in the design of conservation programs:

- Political support for various conservation programs is often enhanced by a diffuse distribution of investments, rather than a targeting of those investments where they yield the greatest results.
- Often, one program is statutorily required to achieve multiple objectives, but the relative importance of the different objectives is left to agency interpretation. In some cases, agencies deal with this complexity with a relatively arbitrary index that combines information related to the various objectives. The weights given to various factors are often decided by those immediately concerned with the program, rather than by objective estimates of the importance of each factor to conservation outcomes.
- Even when cost is considered, it is often only one variable rather than the denominator in a cost-effectiveness calculation. Because the weight given to the cost factor is chosen by those immediately concerned with the program, or out of political considerations, there is a tendency to weight benefits more heavily than environmental or other costs, which results in a flawed assessment.
- The benefit evaluated is often not a true outcome-based measurement but an interim metric. For instance, an agency might evaluate the number of acres in which a new practice to reduce nitrogen (N) runoff has been adopted, rather than the actual change in N runoff. Some level of performance monitoring is needed for at least a sample of sites.
- There is generally little consideration of additionality (does the conservation action affect the environment beyond the changes occurring in other control sites?) and leakage (does the conservation action on one site cause negative conservation outcomes on other sites?).

BOX V-2: COST-EFFECTIVE STRATEGIES FOR REDUCING NUTRIENT RUNOFF

Targeting conservation actions to be as cost-effective as possible could dramatically reduce the cost of achieving given environmental goals. Examples of the potential for targeting investments to enhance effectiveness can be found by considering the environmental goal of reducing nutrient loading in the water delivered by rivers to the sea, which creates zones of hypoxia (low oxygen) that reduce valuable fish and shellfish populations (as seen, for examples, in the Gulf of Mexico or the Chesapeake Bay). The hypoxia results from an excess of the nutrients nitrogen (N) and phosphorus (P), which comes primarily from non-point sources such as agriculture in the watersheds that drain into bays and gulfs.

Because fertilizer is relatively inexpensive, compared to the expected improvements in production and therefore farm income, farmers seem to have a positive economic incentive to over-apply fertilizer containing N and P that is not countered by having to bear the costs of pollution in downstream ecosystems. Government approaches to reducing fertilizer inputs can have the desired impact of reducing nutrient pollution, but key questions are where and how those investments should be made.

One major study found that nutrient loading into the Mississippi watershed and thus the Gulf of Mexico could be reduced by 19% through a geographically focused mix of two strategies: (1) regulations that require best-management practices involving precision N application only when and where it is most needed; and (2) creating small wetlands or riparian forests that temporarily capture runoff and allow denitrification to occur naturally, thereby reducing the nutrient load of the water leaving the wetland by 40 to 90 percent. Importantly, this NOAA analysis indicated that policy mechanisms that target actions where they achieve the greatest cost-effectiveness can be an order of magnitude more efficient in achieving desired outcomes than current practices, which are governed by marginal costs of N pollution and local soils and hydrology rather than cost-effectiveness.

In another study, the World Resources Institute demonstrated, in the Conestoga watershed in Pennsylvania, that a reverse auction strategy was much more cost-effective in the same watershed than the traditional Environmental Quality Incentives Program (EQIP) allocation method. Funded under the Farm Bill, EQIP funds are spread out over several states and counties for equity reasons. In the reverse auction, multiple sellers compete to provide services (environmental outcomes) to a single buyer, who channels investments towards farms on which the greatest outcome is achieved per dollar. In this case, the reverse auction resulted in a seven-fold increase in P runoff reduction per dollar spent compared to EQIP allocation.

Sources:

NOAA Coastal Ocean Program (1999). *Decision Analysis Series No. 20. Evaluation of the economic costs and benefits of methods for reducing nutrient loads to the Gulf of Mexico. Topic 6: Report for the integrated assessment on hypoxia in the Gulf of Mexico.* Retrieved from http://www.epa.gov/owow_keep/msbasin/pdf/hypox_t6final.pdf

Conservation Effects Assessment Program, USDA. (2010). *Assessment of the effects of conservation practices on cultivated cropland in the upper Mississippi River Basin.* Retrieved from http://www.nrcs.usda.gov/technical/nri/ceap/umrb/index.html

National Research Council. (2009). *Nutrient control actions for improving water quality in the Mississippi River basin and northern Gulf of Mexico.* Retrieved from http://www.nap.edu/catalog.php?record_id=12544

National Research Council. (2008). *Mississippi River water quality and the Clean Water Act: Progress, challenges, and opportunities.* Retrieved from http://www.nap.edu/catalog.php?record_id=12051

Selman, M., Greenhalgh, S., Taylor, M., & Guiling, J. (2008). Paying for environmental performance: Potential cost savings using a reverse auction in program sign-up. *WRI Policy Note, 5,* 1-10. Retrieved from http://www.wri.org/publication/paying_for_environmental_performance_reverse_auctions_in_program_signup

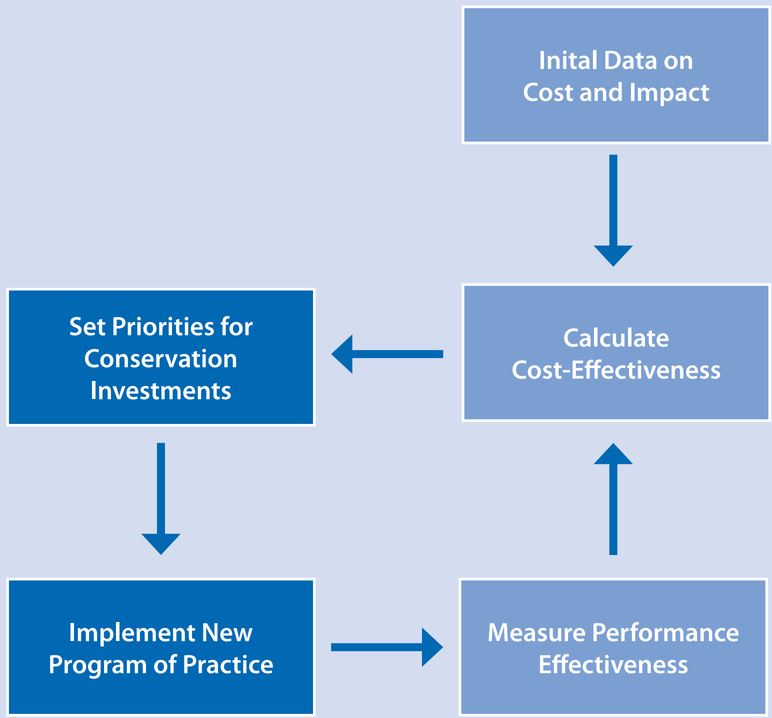

Figure V-1. Current conservation program expenditures are often based on the sequence of gray boxes: priorities are set without due consideration of their cost effectiveness and the actual environmental performance of the investment is not measured. Significant improvements in the conservation impact of these programs can be achieved by including an explicit consideration of the cost-effectiveness in the initial determination of priorities, rigorous measurement of the performance of the changes in practice, and then feedback of this performance measurement into planning for future conservation investments.

The EBI includes a cost factor, including the farmer's bid, which is essentially the cost to the government of the conservation easement. The weighting for the cost factor varies but is typically about one-third of the total score. Studies have shown that the sites enrolled in CRP have increased in EBI over time, which implies that the USDA has gotten better at selecting the more environmentally important sites for project activities. Although the CRP has a relatively robust way of evaluating conservation return, its methods may have room for improvement. For example, if instead of an index, the entire analysis was done in economic terms (the costs in dollars and the benefits in dollars), then there would be less reliance on a single number that sums what can seem like "apples and oranges" with rather arbitrary weightings. In addition, one study[103] found that the process by which CRP handles bids results in paying 10 to 40 percent above the theoretical minimum price the government could pay for the easement.

103. Kirwan, B., Lubowski, R. N., & Roberts, M. J. (2005). How cost-effective are land retirement auctions? Estimating the difference between payment and willingness to accept in the Conservation Reserve Program. *American Journal of Agricultural Economics, 87*(5), 1239-1247.

The **Environmental Quality Incentives Program** (EQIP)[104] is a program that pays producers for undertaking management practices that have some environmental benefit. Authorized at $1.75 billion in 2012, EQIP replaced several other programs, notably the Agricultural Conservation Program. Like its predecessor, EQIP's organizational structure is decentralized, and its money is partitioned to state Natural Resources Conservation Service (NRCS) committees, each of which has its own methodology for determining which practices are funded and where.

EQIP funds are generally less targeted than CRP funds. For instance, in 2006 the Government Accountability Office (GAO)[105] noted that the allocation of EQIP funds to states was determined by 31 variables, which are presumed to be related to need (e.g., acres of irrigated land), along with other weights, to create a combined metric. The GAO study recommended that USDA demonstrate how the EQIP funding formula maximized benefit to society or used some other consistent rationale.

Currently, USDA is moving toward evaluating the performance of EQIP relative to outcome-based national goals, such as the amount of water saved by improved irrigation efficiency. Still, EQIP faces legislative limitations on its ability to target funds; for example, it cannot consider the cost of various bids when evaluating which to fund. It also includes Congressional mandates that direct funds to particular states or regions without a consideration of effectiveness of those expenditures.

Return on Investment is Already Federal Policy

Under the Executive Order on Federal Leadership in Environmental, Energy, and Economic Performance (Executive Order [EO] 13514), signed by President Obama on October 5, 2009, Federal agencies were asked to develop, implement, and annually update a plan that prioritizes actions to meet energy, water, and waste reduction targets based on return on investment to the American taxpayer.

To date, however, the implementation of EO 13514 has been focused on agency operations, primarily on greenhouse gas emissions and water use. It has not yet been interpreted to include major conservation programs implemented by agencies. For example, the Strategic Sustainability Performance Plan released in September 2010 by USDA does not include considerations of whether conservation payments under the Farm Bill have been allocated to priorities that maximize their cost-effectiveness. Nor does the plan released by the Department of Interior evaluate the cost effectiveness of funds used for endangered species conservation or funds for land protection under the Land and Water Conservation Fund.

Including considerations of the cost-effectiveness of funds spent on biodiversity conservation and ecosystem sustainability under EO13514 is an opportunity to improve environmental outcomes of conservation investments. Unlike recurring agency costs for land management or staffing, which are geographically constrained by the location of public lands or management personnel, conservation investments can be targeted where they make the greatest difference. Through the use of a cost-effectiveness analysis, differences among environmental outcomes can be compared and better choices made for the sustainability of the Nation's land and water. For example, our scientific understanding of

104. Natural Resources Conservation Service. *Environmental Quality Incentives Program.* Retrieved from http://www.nrcs.usda.gov/programs/eqip/

105. Government Accountability Office. (2006). *Agricultural conservation: USDA should improve its process for allocating funds to states for the Environmental Quality Incentives Program: report to the Ranking Democratic Member, Committee on Agriculture, Nutrition, and Forestry, U.S. Senate.* Washington, DC: GAO.

hydrology and nutrient dynamics is now sufficiently robust that it is possible to use models of nutrient flows to generate quantitative assessments of where one can get the greatest reduction in nutrient loading into the Mississippi (see Box V-2) with the lowest tradeoff of reduced yields or federal expenditures.[106, 107] As the science for valuing biodiversity and ecosystem services continues to improve, these performance measures can be converted into their dollar values, allowing a more formal "return on investment" calculation.

Performance Effectiveness

The use of cost-effectiveness measures to target investments requires setting priorities based on expected results and then evaluating the "performance effectiveness" (PE) of those investments, so that cost-effectiveness calculations can be modified accordingly. An example of PE monitoring of the type meant here is shown in Box V-3, where it is providing crucial feedback for adaptive management.

BOX V-3: PERFORMANCE EFFECTIVENESS OF CONSERVATION INVESTMENTS

The Conservation Effects Assessment Program (CEAP) is showing the value of performance effectiveness monitoring of a conservation program in the Upper Mississippi River Basin.

The Mississippi River Basin Healthy Watersheds Initiative (MRBI) of the Natural Resources Conservation Service aims to help producers in targeted watersheds maintain agricultural productivity and at the same time implement conservation practices that avoid, control, or trap nutrient runoff. The basins being targeted cover only 20% of the total land area of the Mississippi River Basin, but they contribute the majority of the nutrient load flowing downstream to the Gulf of Mexico, where it contributes to hypoxia and fish kills (see Box V-2). Projects are awarded on a competitive basis and the conservation results are monitored over time by the Conservation Effects Assessment Program (CEAP).

CEAP site measurements found that the improvements in agricultural practices were approximately five times more effective for some sites in the Mississippi Basin than for other sites. The average reduction in nitrogen (N) runoff after adoption of improved practices was 39 lbs N/acre from 8.5 million acres on which the changes were made. However, runoff from another 22.2 million acres was reduced by only 9 lbs N/acre.

This performance effectiveness measurement provides crucial feedback for future calculations of the return on investment and thus for adaptive management, and improving targeting of the conservation investment.

Sources:

Alexander, R. B., Smith, R. A., Schwarz, G. E., Boyer, E. W., Nolan, J. V., & Brakebill, J. W. (2007). Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. *Environmental Science and Technology, 42*, 822-830. DOI: 10.1021/es0716103 and http://water.usgs.gov/nawqa/sparrow/gulf_findings/

Mississippi River Basin Healthy Watersheds Initiative (MRBI) Retrieved from http://www.nrcs.usda.gov/programs/mrbi/mrbi_overview.html

National Research Council. (2009). *Nutrient control actions for improving water quality in the Mississippi River basin and northern Gulf of Mexico.* Retrieved from http://www.nap.edu/catalog.php?record_id=12544

106. Donner, S.D., & Kucharik, C. J. (2008). Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. *Proceedings of the National Academy of Sciences 105(11)*: 4513–4518.

107. Donner, S.D., Kucharik, C. J., & Foley, J. A. (2004). Impact of changing land use practices on nitrate export by the Mississippi River. *Global Biogeochemical Cycle, 18,* GB1028, doi:10.1029/2003GB002093

It is currently rare that the PE of management interventions is adequately assessed to determine whether the intended environmental outcome was achieved, because monitoring programs often focus on changes in management practices instead of the outcomes of those changes. For example, the Natural Resource Conservation Service (NRCS) keeps extensive records of the changes in agricultural practices of farmers who have enrolled in conservation programs such as EQIP or CRP. But, historically, NRCS has not supported monitoring to assess the impact those changes have had on water quality or biodiversity conservation.

Recommendations

- **Federal agencies that implement biodiversity and ecosystem conservation programs should prioritize expenditures based on their cost-effectiveness.**
- **All conservation programs (e.g., Title 2 Farm Bill programs, mitigation payments, etc.) should be reviewed, and identification should be made of those which will be subject to this recommendation.**
- **Agencies, whenever possible, should report annually on the alignment of their expenditures with their conservation priorities.** The reports should describe: (1) why they chose to use a particular method for determining investment effectiveness; (2) how the methodology takes account of additionality, leakage, and potentially countervailing actions by other government programs; (3) a clear rationale for weightings used in aggregate indices; and (4) the current status and need for Performance Effectiveness monitoring associated with conservation programs.
- **For the short term, agencies should begin by focusing on existing programs where maximum conservation benefits would be expected,** such as incentive payments that influence behaviors on private land, or area-based management.

VI. Learning More: Biodiversity and Other Ecosystem Attributes

A central challenge for the U.S. science agencies is prediction of the path and consequences of anthropogenic ecosystem change. By definition, such change is forced by human behavior, but describing its causes and predicting its future course require an understanding of the components and function of ecosystems through time, the mechanisms that connect human behavior with the living and physical environments, as well as an understanding of the dynamics of the coupled system.[108]

The need for prediction is embedded in the missions of a number of agencies (see Table III-1). The science strategy of the U.S. Geological Survey (USGS),[109] as one example, includes the following central objectives:

- Understanding ecosystems and predicting ecosystem change
- Clarifying the record on climate change and assessing consequences
- Assessing national hazards, risk, and resilience
- Identifying environmental risk to public health
- Quantifying, forecasting, and securing supplies of fresh water

Having the capacity to make conditional predictions of ecosystem change makes it possible to develop strategies for the sustainable management of complex systems that may fluctuate within bounds, as well as to undertake scenario planning to prepare responses to uncertain conditions within those bounds.[110,111] Exercises of this kind have been used to evaluate regional environmental management options in several parts of the United States (e.g., the Willamette Basin of Oregon, Puget Sound, Chesapeake Bay).[112] Until now, however, such exercises have not been done for the nation as a whole.[113]

One reason for this is that a comprehensive ability to accurately model anthropogenic environmental change has not yet been achieved. Such predictive models as do exist at both national and global scales are not completely sound because their projections are based almost exclusively on Earth observations made by satellite—they do not include social observations, nor ground-based ecological observations.

108. Carpenter, S. R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., . . . Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences 106,* 1305–1312.

109. U. S. Geological Survey. (2007). *Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007 –2017*. Retrieved from http://pubs.usgs.gov/circ/2007/1309/pdf/C1309.pdf

110. Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario planning: A tool for conservation in an uncertain world. *Conservation Biology, 17,* 358-366.

111. Bartholomew, K. Land use-transportation scenario planning: promise and reality. *Transportation, 34,* 397-412. doi: 10.1007/s11116-006-9108-2

112. Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., . . . Shaw, M. R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7, 4–11. doi:10.1890/080023

113. Guerry, A., Plummer, M., Ruckelshaus, M., & C. Harvey. (2011). Ecosystem service assessments for marine conservation. In Kareiva, P., Tallis, H., Ricketts, T.H., Daily, G.C., & Polasky, S. (editors). *Natural capital: Theory and practice of mapping ecosystem services* (Chapter 17). Oxford: Oxford University Press. Retrieved from http://www.oup.com/us/catalog/general/subject/LifeSciences/Ecology/?view=usa&sf=toc&ci=9780199588992

Human behavior is treated as a largely exogenous driver of environmental change; neither human decision processes nor the ways in which decisions change in response to feedbacks from the environment are included in the models. This inadequacy of current models is exacerbated by a failure to tie together space-observed ecosystem characteristics with ground-based observations of the same or other characteristics and the roles of distinct, biological ecosystem components (these are usually treated, if at all, as a "black box" in the models' calculations). Not only is a much greater level of sophistication is needed for these models (see Chapter VIII), but the data necessary to inform them are incomplete.[114]

In this chapter, we describe three types of data and information that are required to make it possible to assess (see Chapter III) and predict change in order to facilitate adaptation, inform modification of policy, and guide new management strategies. Each of these information types is required for sound predictive modeling, and is also needed to achieve other goals outlined elsewhere in this report—monitoring data are needed for assessments, 'social precursors' data are needed in ecosystem services valuation (see Chapter VII), and biodiversity inventory data are needed to better understand ecosystem function, status, vulnerability, and threats. Of course, the mere collection of data without application of the sophisticated informatics tools now available would be wasteful, and therefore this chapter calls out EcoINFORMA (see Chapter VIII) in its recommendations for handling and making the data available for use.

Information Needs 1: The 'Social Precursors' of Ecosystem Change

Better understanding of changes in the determinants of peoples' behavior (such as price expectations or social norms) and the feedbacks between behavior and ecosystem change would enable Federal agencies better to predict anthropogenic environmental change that threatens biodiversity preservation, ecosystem services, and biosecurity. Three questions are important here:

- Are current modeling methods adequate to predict the consequences of human-ecosystem dynamics for biodiversity preservation, for ecosystem services, and for biosecurity?
- What is the scope for using socio-economic data in modeling anthropogenic environmental change?
- How can existing monitoring systems be augmented to include such data?

Incorporation of human behavior into predictive modeling requires an understanding of the factors that drive human resource use decisions. It also requires observations on those factors. People make decisions affecting the future state of the environment on the basis of a range of social indicators. These include prices and price trends, expected changes in the regulatory environment, changes in social norms and preferences. These are the "social precursors" of environmental change (Table VI-1).

114. The H. John Heinz III Center for Science, Economics, and the Environment. (2006). *Filling the gaps: Priority data needs and key management challenges for national reporting on ecosystem condition.* Retrieved from http://www.heinzctr.org/Programs/Reporting/Working%20Groups/Data%20Gaps/Gaps_LongReport_LoRes.pdf

Table VI -1. Social precursors that correspond to specific drivers of ecosystem change. These precursors anticipate ecosystem change through their effect on the decisions (socio-economic mechanisms) leading to ecosystem change.

Drivers of Ecosystem Change	Ecosystem Impacts	Socio-economic Mechanisms	Social Precursors
Land use change	Habitat conversion and fragmentation, water diversion, soil, water and air pollution, change in species abundance and richness; impacts on ecosystem processes and services	Investment/disinvestment in particular land uses, development of new infrastructure, technological change	Commodity prices, input prices, land prices, interest rates, taxes, subsidies, investment grants, zoning restrictions, regulations, access rules and fees
Trade, transport, travel	Invasion by alien species leads to change in species abundance and richness (local extirpation); impacts on ecosystem processes and services	Dispersal of harmful pests and pathogens as items of trade or 'passengers' on traded goods or transport vessels	International commodity prices, transport fuel costs, tariffs, trade restrictions, inspection and interception regimes
Overexploitation of wild living species	Change in species abundance because of overharvest, by-catch, and food web effects; impacts on ecosystem processes and services	Direct depletion through harvest	Access rules and restrictions, commodity prices, environmental social norms on consumption of wild living species
Climate change	Change in species distribution resulting from changes in temperature and precipitation lead to changes in structure and processes of terrestrial and marine ecosystems, and thence to changes in ecosystem services	Emissions of greenhouse gases (GHGs) from industrial, transport and agriculture (including forest conversion); reduction in carbon sequestration from land use change	Energy and commodity prices, land prices, access rules, international agreement, IPCC assessment reports

The problems posed by rapid anthropogenic ecosystem change require a significant improvement in our capacity to model and predict interactions between the socio-economic system and the biophysical environment. The non-probabilistic scenarios that have commonly been the only forward-looking component of international global change assessments illustrate one dimension of the problem. Because the strategies used to structure each scenario are typically assumed to be insensitive to the environmental changes they induce, the associated projections are necessarily biased. Without formally treating the set of feedback mechanisms that make up the social system, it is not possible to evaluate alternative strategies, to trace their impacts across the coupled system, or to test the stability of the system under each potential strategy. Without attaching probabilities to the outcomes identified within the model, it is not possible to judge the efficacy of actions designed to alter the likelihood of an outcome (mitigation) against those designed only to alter its cost (adaptation).

To increase the predictive power of models of anthropogenic ecosystem change, longer-term goals should be: (1) to ensure that the socio-economic data needed to inform predictive models of anthropogenic environmental change are routinely collected by relevant Federal agencies; (2) to integrate socio-economic data with data deriving from space- and ground-based earth observations; and (3) to provide the research community, through the major research funding agencies, with the incentives and resources needed to develop capacity to predict anthropogenic environmental change.

Databases that include many of the social precursors of anthropogenic ecosystem change already exist. They include, for example, land and commodity prices, taxes, zoning restrictions, regulatory frameworks, social norms of behavior, and so on. Some are already reported in Data.gov, including producer and export/import price indices and futures trading. Many are spatially explicit (e.g., land prices) or apply to well-defined areas (e.g., zoning restrictions) and so may be integrated with spatially explicit earth observations. Many of these datasets derive from a variety of public sources, although several are provided commercially (e.g., through Google Earth®).

There is, however, no consistency across data sets, and even if they are internet-accessible, they are neither integrated nor interoperable: they are subject to different access rules, and are held in multiple locations for different periods and at different levels of disaggregation. And, they are characterized by numerous incompatible legacy systems and data formats. There is a need for agencies that manage and regulate ecosystems to generate additional ground-based, spatially explicit datasets on trends in the factors and drivers (e.g., demography, trade, economic incentives, subsidies, etc.) associated with human activities that significantly alter ecosystem structure and processes, and therefore services, to complement space-based observations. Even more importantly, data integration, especially "vertical" integration—the ability to tie ground-truth data in several disciplines together with satellite-collected data—must be facilitated by EcoINFORMA, so that they can be shared globally (for instance, through the GEO BON). Please see Chapter VIII for discussion of these issues.

Information Needs 2: Monitoring of Land Use, Habitats, and Ecosystem Processes

A second set of information needs is for timely, interoperable, ground-based ecological and environmental data. Many of the monitoring programs that record these conditions and processes (see Appendix A) collect data only at very long intervals and do not report those data immediately. The National Land Cover Database (NLCD),[115] for example, provides some foundation for environmental assessment, but its data are updated every five years at best, and many of its descriptions are not sufficiently fine-grained to be useful for ecosystem assessment, much less predict change at local scales. In addition, NLCD data are typically made available four to five years after the data are collected, a time lag too large to address rapidly changing environmental features and demands. Other monitoring programs (see Appendix A), assessments (see Appendix B), and programs also provide some data, but the informatics infrastructure to link them together and analyze pooled data in an interoperable environment does not exist. This is one of the major reasons that this Working Group is so adamant that EcoINFORMA is needed. The usefulness to governmental agencies of the capabilities described in Chapter VIII has been demonstrated in Mexico by CONABIO (see Box VI-1).

115. See National Land Cover Database (1992-2001): http://pubs.usgs.gov/of/2008/1379/; NLCD 2011 is planned.

BOX VI-1: CONABIO—AN 'HONEST BROKER' FOR ECOLOGICAL DATA IN MEXICO

An excellent model of a government agency that effectively tracks and handles information about a country's biodiversity and ecosystems is the National Commission for Knowledge and Use of Biodiversity (CONABIO) in Mexico. CONABIO is a permanent inter-ministerial commission of the Mexican government, established in 1992, which is chaired by the President of Mexico. Its permanent secretary is the head of the Department of Environment and Natural Resources. The heads of nine other cabinet-level departments, including Energy, Public Education, Foreign Affairs, Health, and Tourism are also members, indicating the value that Mexico places on the proper management of its biodiversity. CONABIO also guides Mexico's activities in relation to international biodiversity commitments, such as the Convention on Biological Diversity (CBD).

CONABIO, widely and justifiably recognized as an honest broker, develops Mexico's national ecological informatics capacity, and uses it to promote, coordinate, and support regulatory and management activities of other government agencies. It supports basic research, compiles available information, and serves as a public source of information and guidance on how it can be effectively applied. It also functions as a bridge between academia, government, and society in helping the sectors understand local problems and deal with them sensibly. Inspired by its effectiveness, a dozen Mexican states have established or are considering establishing their own versions of CONABIO.

Among CONABIO's specific responsibilities are operating the National Information System on Biodiversity (SNIB), allowing the Commission to provide information and advice to Mexican and foreign bodies about Mexico's biodiversity. SNIB contains 4.3 million records of specimens of Mexican organisms held in national and foreign museum collections, all of them quality controlled and geo-referenced, and the number of such records is growing by more than 100,000 per year. This information is used to provide high-quality, real-time advice on the potential and actual damage to biodiversity by fires, hurricanes, and other disasters, as well as development plans or other alterations of land use. Another important benefit of the database is the ability to map the spread of invasive species and their effect on native ecosystems, which helps enable effective control mechanisms. In these ways, CONABIO provides a solid foundation for the conservation and sustainable use of Mexican biodiversity.

CONABIO's budget situation reflects the high regard in which it is held. For its first 16 years, the budget was about $4.5 million annually; for the last two years, however, largely because of the support of the President, the budget was trebled to more that $14 million per year. Similar national-level organizations are operated by Costa Rica, Colombia, and Australia, and are being developed or planned elsewhere.

The Federal government's capacity for monitoring and reporting on environmental trends is large and highly professional, but it is also distributed (see Table III-1) to an extent that reduces its potential effectiveness. As a rule, each individual agency or organization collects data according to its own mission and makes use of the data via management techniques and strategies that serve its own particular needs.[116] One weakness of this fragmented system is that it hampers attempts to implement national monitoring priorities—to make new investments, re-allocate existing resources, or promote integration

116. The H. John Heinz III Center for Science, Economics, and the Environment. (2006). *Filling the gaps: Priority data needs and key management challenges for national reporting on ecosystem condition*. Retrieved from http://www.heinzctr.org/Programs/Reporting/Working%20Groups/Data%20Gaps/Gaps_LongReport_LoRes.pdf

of methods. This weakness, in turn, inhibits the ecological monitoring needed for sound environmental management. Moreover, recent budget cuts are causing some agencies to reduce the scope of monitoring at a time when the need to intensify those efforts is growing dramatically.

The system for monitoring water quality in the United States serves as an example. Of all natural processes essential to ecosystems and maintenance of life, the availability and quality of fresh water is paramount. Yet national data on water flows and water quality contain major gaps. The National Water Quality Assessment Program (NAWQA)[117] is the most comprehensive national database, yet only 41 drainage basins, representing less than half of U.S. territory, are part of the NAWQA network. This lack of information will become increasingly problematic as climate change affects the distribution of rainfall and demand for water continues to rise. In fact, in its 1998 report[118] on biodiversity and ecosystems, PCAST recommended that spending on monitoring programs should double from its 1995 levels by 2001. As shown in Appendix A, however, even by 2010 such spending had increased only by about 33% (calculated in constant 2005 dollars), an increase that is inadequate to meet needs for data.

Given the pace and scope of environmental change, monitoring of ecological parameters must be frequent and comprehensive, spanning spatial scales from local to global. The effectiveness of techniques to monitor biodiversity and ecosystem services depends on their consistency, continuity, and interoperability. The Nation has an urgent need for more complete monitoring systems in order to inform policy, as a basis for development of predictive capabilities, and to address issues of compliance, assessment, and management. Despite the urgency of these needs, the diversity of agency missions and fragmentation of monitoring efforts (see Table III-1 and Appendix A) reduce the ability to create an effective and coordinated nationwide reporting system that would facilitate the QuEST Assessment (see Chapter III) and other important initiatives. Further, there is critical need for the data to be more rapidly compiled and disseminated than is currently is the case, so that policy makers can "bet and hedge"[119] their actions both promptly and appropriately. In this, this Working Group sees another compelling reason to develop EcoINFORMA (see Chapter VIII), so that data handling could be shared and standardized across agencies to ensure accessibility and interoperability.

---

117. U.S. Geological Survey. *National Water-Quality Assessment (NAWQA) Program.* Retrieved from http://water.usgs.gov/nawqa/

118. PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

119. Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science, 319,* 573-574. doi: 10.1126/science.1151915

Information Needs 3: Discovery and Inventory of Biodiversity

A multiplicity of studies (only a few[120,121,122,123] are cited here) have concluded that ecosystems-focused science that deals with the biological effects of climate change on ecosystem services should place great emphasis on micro-organisms, soil arthropods, marine invertebrates, and fungi. This is because these organisms play a pivotal role in the large-scale flow of energy through complex ecosystems, and they are also often the causative agents in emerging diseases (see Chapter II). Yet, despite the clear importance of the known—and the unknown—species of organisms to both ecosystem and human health and well-being, inventories of them are far from adequate, to say nothing of scientific understanding of their roles in ecosystem function.

Of an estimated total of at least 12 million eukaryotic organisms (plants, animals, fungi) worldwide, the United States is probably home to some 5 percent—perhaps 600,000 species. Only about a quarter of the total estimate have actually been discovered and recorded, and no more than 30,000 species can be considered reasonably well known in terms of their characteristics, habits, and functioning in the ecosystems in which they occur.[124] These estimates are based on comparisons between U.S. and global totals for relatively well-known groups of organisms, such as terrestrial plants, butterflies, and vertebrates. The best-known organisms tend to be those that are large, charismatic, or otherwise appealing or useful to humans, such as the species we eat, hunt, or watch through binoculars.

Unfortunately, the species about which is the least is known are nonetheless known to be the biological engines for many critical ecosystem processes and therefore ecosystem services, such as the purification of water and provision of soil fertility; they are also resources for agriculture, fisheries, public health, and adaptation to climate stress (see Box VI-2). Gaining knowledge of these species would benefit the Nation by elucidating their roles in the ecosystems that provide clean air, water, soils, food, and fiber. But, funding for systematics and taxonomy— the sciences that enable understanding of organismal diversity—are absolutely essential to inventory and characterize these organisms, and lags far behind the need for knowledge.

---

120. Schulze, E.-D., & Mooney, H.A. (1994). *Biodiversity and Ecosystem Function.* New York: Springer-Verlag.

121. PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

122. National Research Council. (2004). *Valuing Ecosystem Services: Toward Better Environmental Decision-making.* Washington, DC: National Academies Press.

123. House of Lords Select Committee on Science and Technology. (2008). *2007-2008 session fifth report: Systematics and taxonomy: follow-up.* Retrieved from http://www.parliament.the-stationery-office.co.uk/pa/ld200708/ldselect/ldsctech/162/16205.htm

124. PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

BOX VI-2: SPECIES GROUPS OF PARTICULAR IMPORTANCE

To the casual observer of nature, the species of most obvious primary interest may well be birds, fishes, mammals, or reptiles—the large, colorful, visually appealing creatures that fascinate in their seeming variety. To the ecologist, however, species groups of particular interest are invisible to the naked eye, more numerous by orders of magnitude, and correspondingly more highly varied. And like the submerged iceberg, this vast and unseen portion of nature becomes more significant—and ultimately important—the more closely one looks.

Soil and sediment invertebrates. The life forms that inhabit soils and freshwater or marine sediments are critical to nutrient cycling, soil and sediment formation, decomposition of organic matter, biocontrol of pests and pathogens, transport and degradation of pollutants, and the provision of clean water. This below-the-surface biodiversity influences the composition of plant communities and provide essential food for other organisms. A proper knowledge of soil organisms and their linkages above ground, as well as their contributions to ecological processes, is essential if Americans are to maintain and manage ecosystems properly and secure the Nation's food supply.

Marine invertebrates. Marine organisms are, in general, even less well known than terrestrial ones, and yet they also are essential to a healthy, productive environment. The Census of Marine Life recently published an overview of the state of knowledge of marine taxa, which lists about 250,000 marine species. As is readily admitted by the authors of the overview, this Census constitutes only a modest beginning, and scientists lack sufficient understanding of most marine ecosystems even evaluate their sustainability under current conditions or predict it for the future.

Fungi. While more than 1.5 million fungal species are thought to exist globally, fungi are extremely poorly known and few scientists anywhere are studying their diversity. Along with bacteria and invertebrates, fungi are the decomposers of the biosphere, breaking down organic material and making nutrients available to new plant growth. Fungi are also major pathogens of plants, animals, and human beings. Fungi should be targeted for intensive exploration and inventory.

Bacteria. Bacteria, ubiquitous on Earth, constitute much of the world's biomass and exhibit metabolic diversity far greater than that of any other group of organisms. This diversity allows them to survive in extreme habitats, such as deep in the soil, under vast ice caps, in near-boiling hot springs, and in highly saline environments where no other known life forms survive. They are vital in recycling nutrients, and the genes and enzymes that make them so versatile also have an obvious and direct commercial importance. Their hardiness and versatility also underlines their importance—and potential menace to humans—as disease-causing organisms. Most bacteria have not been characterized, and a carefully targeted inventory would lead to the discovery of many new species with properties that are economically useful (including novel genes) or ecologically significant.

Sources:

Ausubel, J. H., Crist, D. T., & Waggoner, P. E. (Editors). (2010). First Census of Marine Life: highlights of a decade of discovery. New York: Census of Marine Life International Secretariat. Retrieved from http://www.coml.org/Highlights-2010

PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

The discovery of species could be more efficient than ever before, because of the tools of molecular biology, which can be combined with biochemical, morphological, automated pattern recognition and other methodologies. In principle, these tools make it possible to increase, assemble, and disseminate knowledge about biodiversity rapidly. The one other component that is needed to pull all of this together is informatics capability to enable data interoperability and integration with data and information of other types (such as those discussed above). Again, EcoINFORMA (see Chapter VIII) is envisioned by the working group as the enabler of these developments.

Recommendations

- **The research funding agencies, as well as mission agencies that need predictive models to improve their own performance, should coordinate funding of research on predictive models of anthropogenic environmental change.**
  - Ground-based, spatially explicit observations of socio-economic causes and consequences of ecosystem change should complement space-based observations.
- **EcoINFORMA, the informatics entity proposed in Chapter VIII, should help develop data interoperability among socio-economic data and trends, along with biological, ecological, geophysical, and Earth observation data.**
  - Whenever possible, agencies that manage and regulate the ecosystems of the United States should be encouraged to generate data on trends in the factors and drivers associated with human activities that significantly alter ecosystem structure and processes.
  - The data and the information architecture developed by EcoINFORMA should be made available to international initiatives such as the GEO BON network, to assist in the development of a global system of social markers of ecological change for use in ecosystem modeling.
- **The CENRS should identify the most important temporal and spatial data gaps within existing Federal and regional ecological monitoring systems and clarify agency roles and funding to fill these, and make sure that all data are available through EcoINFORMA.**
  - The CENRS should review existing monitoring networks, and encourage participation in development and deployment of informatics standards in common, and thereby integrate at least the output of the monitoring networks.
  - It is also necessary to increase spatial coverage, and prioritize these recommendations over the near and long terms to guide budget development across the agencies.
- **The CENRS should develop a national strategy for filling gaps in knowledge of the key groups of species identified here (bacteria, fungi, invertebrate animals of soils and oceans).**
  - This strategy can build on surveys already carried out by DOI bureaus, NOAA, NSF investigators, the Smithsonian Institution, and public and private organizations such as NatureServe.

- In-depth sampling and inventory of groups of organisms that are important to ecosystem processes, as well as pathogens, at Federal agency and Federally-funded research and monitoring sites (for example, those of NEON or LTER) should be commissioned by appropriate agencies, and funded at increased levels by NSF, EPA, NASA, NOAA, and USDA, as appropriate.
- The annual OMB-OSTP budget memo should call out these critical gaps as a priority for future funding, and direct that the accumulating data and information be made available through EcoINFORMA.

VII. Learning More: Valuation of Ecosystem Services

Society depends on ecosystems to provide food (animal products, crops, and fisheries), fuels (fuel wood and biofuels), and fibers (clothing and building materials), as well as other services that are outside economic markets. Though it is not often explicitly recognized by society, if ecosystems fail through over-exploitation or other disturbance, society will significantly falter. This Working Group believes that an explicit recognition of the value of ecosystem services will serve society well as it strives to balance competing demands. *Valuation* is the process by which economic and ecological scientists estimate the social importance of non-marketed ecosystem services.

The supply of many of the "provisioning" ecosystem services (food, fiber, fuel) is regulated by private market prices. As in any market, these influence decisions about what and how much should be produced. However, the *environmental* costs of producing foods, fuels, and fibers are usually either incompletely considered by producers, or ignored altogether, and therefore are not reflected in market prices. Environmental costs include, for example, the forgone public benefits of ecosystem services, such as filtration of water or flood control, that are disrupted when land is cleared to produce foods, fuels, and fibers. In economists' terms, such costs are "externalities"—effects that arise from production or consumption of goods or services for which no appropriate compensation is paid. Because ecosystem services do not have a price tag, they are often not directly valued in any way and are not a factor in the decisions of landowners.[125,126] The non-marketed nature of ecosystem services poses a problem for both science and policy. The problem for science is to estimate the value of ecosystem services, and the problem for policy is to use such estimates in developing ecosystem management strategies where markets for ecosystem services are incomplete (e.g., grain prices do not reflect impacts of grain production on water quality) or are missing altogether (e.g., the contribution of watershed vegetation to water quality and quantity is priced at zero).

In this chapter, we briefly review the current status of ecosystem services valuation, and the policy areas in which it is being applied; the progress and needed directions of ecological-economic research, and how that is intersecting with developing policy and management; and some of the recent activities of Federal agencies (in some cases with academic and NGO partners) that incorporate ecosystem services valuation as one factor in decision-making. Our final set of observations concern accounting for the Nation's environmental capital, or ecological wealth, as a part of the overall system of economic accounts. The recommendations at the end of the chapter are based on our conclusion that valuation has great potential to inform policy and management strategies that will help sustain ecosystem services to society in the United States.

125. Carpenter, S. R., DeFries, R., Dietz T., Mooney, H. A., Polasky, S., Reid, W. V., & Scholes, R. J. (2006). Millennium Ecosystem Assessment: Research needs. *Science, 314,* 257-258. doi:10.1126/science.1131946

126. National Research Council. (2004). *Valuing ecosystem services: Toward better environmental decision making.* Retrieved from http://www.nap.edu/catalog.php?record_id=11139

Current Estimates of Ecosystem Services Values

While the science of valuation is now reasonably mature, there are as yet no well-founded global estimates of the value of environmental externalities, in particular of externalities linked to biodiversity loss. Indeed, a striking feature of recent global assessments of biodiversity and ecosystems is that they have been unable to measure the social importance of most of the observed changes. The highly respected *Millennium Ecosystem Assessment*,[127] for example, reported that 60 percent of all ecosystem services had declined in physical terms, but was unable to attach a value to the decline in any one service.

The recently published assessment *The Economics of Ecosystems and Biodiversity* (TEEB)[128] reviewed the range of estimates contained in studies of marketed and non-marketed ecosystem services deriving from particular ecosystem types (Table VII-1). TEEB showed that the marginal value of a change in ecosystem services is extremely sensitive to socio-economic conditions.

Table VII-1. The range of estimates of willingness to pay for ecosystem services, by biome.

	Minimum $/ha/yr				Maximum $/ha/yr			
	Provisioning	Cultural	Regulating	Habitat	Provisioning	Cultural	Regulating	Habitat
Coral Reefs	6	0	8	0	28892	1084809	33640	56137
Open oceans	8	0	5	0	22	0	62	0
Coastal systems	1	0	170	77	7549	41416	30451	164
Coastal wetlands	44	10	1914	27	8289	2904	135361	68795
Inland wetlands	2	648	321	10	9709	8399	23018	3471
Rivers and lakes	1169	305	305	0	5776	2733	4978	0
Tropical forests	26	2	57	6	9384	1426	7138	5277
Temperate forests	25	1	3	0	1736	96	456	2575
Woodlands	7	0	9	0	862	0	1088	0
Grasslands	237	0	60	0	715	11	2067	298

Source: Kumar, P. (Ed.). (2010). *The Economics of Ecosystems and Biodiversity.* London, UK: Earthscan.
Note: ha = hectare

For example, the value of land management for water supply[129] in the Catskills-Delaware watershed, the poster child of payments for ecosystem services (PES) in the United States, is high because the watershed serves a metropolitan area of 19 million people[130] in and around New York City. Moreover, those urban residents have the capacity to pay for the technological substitute—an expensive water filtration plant—so that the avoided cost of the plant can be used as a way of quantifying the value of

127. Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: General synthesis.* Washington, DC: Island Press.

128. Kumar, P. (Ed.). (2010). *The Economics of Ecosystems and Biodiversity.* London, UK: Earthscan.

129. U.S. Environmental Protection Agency. *A Landscape Analysis of New York City's Water Supply.* Retrieved from http://www.epa.gov/nerlesd1/land-sci/ny.htm

130. The metropolitan area as defined by the U.S. Office of Management and Budget as the New York-Northern New Jersey-Long Island, New York-New Jersey-Pennsylvania Metropolitan Statistical Area (MSA) had an estimated population of 19,069,796 as of 2009.

land restoration and other management. By contrast, the value of land management in a catchment of similar size elsewhere would generally be much lower.

What is most noticeable about the range of estimates reported in Table VII-1 is that, in the upper limit, what the *Millennium Ecosystem Assessment* calls "regulating" ecosystem services (e.g., water purification, flood control, and climate stabilization, all of which are generally outside the market) typically dominate the provisioning services (which are generally inside the market). To illustrate how economically important the regulating services can be, we note that extrapolation from the results of models of long-term economic costs of climate change by sector[131] indicate the global cost of crop genetic diversity loss (one form of biodiversity loss) in agro-ecosystems alone—measured in terms of the capacity of agriculture to adapt to changing environmental conditions—could potentially be as high as 5 percent of global GDP.[132] In spite of such evidence, the value of biodiversity conservation is not generally taken into account in most climate adaptation strategies.

Current Policies Regarding Environmental Costs

When ecosystem services and the conditions that enable them are neither transacted in markets nor protected by public policy, they will be undervalued. Ultimately, this undervaluation will lead to deterioration of ecosystems through exploitation, and thus to deterioration of the quantity and quality of the services that people receive. A primary aim of environmental policy should be to 'internalize' environmental externalities: to confront resource users with non-market costs they impose, or to compensate them for non-market benefits they confer on others.

The United States has long experience with the use of economic instruments to persuade people to take environmental costs into account.[133] These include taxes, royalties, access fees or charges, tradable permits, deposit-refund systems, environmental bonds, and liability rules.[134] More recently, attention has focused on instruments to compensate resource users for the benefits they confer on others. These instruments are collectively referred to as "payments for ecosystem services," or PES, and are particularly relevant to the protection of biodiversity and ecosystems.[135] The U.S. has effectively been implementing payments for biodiversity protection since the 1970s. Two offset programs initiated at that time (implemented by the U.S. Fish and Wildlife Service, the National Marine Fisheries Service and the California Department of Fish and Game), are wetland and stream credit banking, and endangered species (now conservation) banking. Payments in these schemes take the form of compensation funds. The U.S. currently has seven active biodiversity banking programs involving approximately 700,000

131. Stern, N. H. (2007). *The economics of climate change: The Stern review.* Cambridge, UK: Cambridge University Press. Retrieved from http://www.cambridge.org/gb/knowledge/isbn/item1164284/?site_locale=en_GB

132. Perrings, C. (2010). Biodiversity, Ecosystem Services, and Climate Change: The Economic Problem. *Environment Department Papers.* Washington, DC: World Bank

133. Stavins, R.N. (2003). Experience with Market-Based Environmental Policy Instruments. *Handbook of Environmental Economics* (ed. By K.-G. Mäler & J.R. Vincent), pp 355-435. Amsterdam, Netherlands: Elsevier

134. U.S. Environmental Protection Agency. (2001). *The United States Experience with Economic Incentives for Protecting the Environment.* Washington, DC: U.S. Environmental Protection Agency

135. Ferraro, P. & Kiss, A. (2007) Direct payments to conserve biodiversity. *Science, 298,* 1718-1719.

acres and payments of between $1.5 and $2.4 billion annually.[136] Other countries are now developing PES schemes, some of which are expected to yield biodiversity benefits.[137]

Such schemes recognize that the most effective means of conserving valuable natural assets is often to securitize them: to assign development rights to corporations or public-private sector partnerships in exchange for the conservation and management of threatened ecosystems.[138] The creation of markets provides people with an incentive to reduce activities with high external costs and to increase activities with high external benefits; to conserve natural assets whose value is growing and to convert assets whose value is declining. To summarize the options:

- Where assets are held **privately**, and where people's use of those assets generates externalities, a wide range of economic instruments are potentially available to limit the damage—including environmental taxes, non-compliance fees, and penalties.[139]
- Where assets are held in **public** trust, as is the case with state, National Forest, National Parks, Bureau of Land Reclamation, Fish and Wildlife, and Department of Defense lands, and where these assets generate services whose benefits are **privately capturable**, there is scope for levying user charges, access fees, or environmental bonds (deposit-refund systems), as appropriate.
- Where assets are held **privately**, but generate services whose benefits are **public goods**, there is scope for developing markets via systems of PES.[140,141] Payments schemes can provide incentives to private resource users to adopt land-use practices that confer benefits or reduce costs borne by the general public.
- Where market-based instruments developed for other purposes have negative environmental effects, as many agricultural subsidies do, there is scope for either removing the harmful subsidy[142] or for introducing a specific instrument to mitigate the environmental harm (see Chapter V).

136. Madsen, B., Carroll, N., & Moore Brands, K. (2010). *Offset and Compensation Programs Worldwide.* Washington, DC: Ecosystem Marketplace

137. Rands, M. R. W., Adams, W. M., Bennun, L., Butchart, S. H. M., Clements, A., Coomes, D., Entwistle, A., Hodge, I., Kapos, V., Scharlemann, J. P. W., Sutherland, W. J., & Vira, B. (2010). Biodiversity Conservation: Challenges Beyond 2010. *Science, 329,* 1298-1303.

138. Chichilnisky, G. & Heal, G. (2000). *Environmental markets: Equity and efficiency.* New York: Columbia University Press

139. European Environment Agency & the Organisation for Economic Co-operation and Development (OECD). *OECD/EEA database on instruments used for environmental policy and natural resources management.* Retrieved from http://www2.oecd.org/ecoinst/queries/index.htm

140. Ferraro, P., & Kiss, A. (2007). Direct payments to conserve biodiversity. *Science, 298,* 1718-1719. doi:10.1126/science.1078104

141. Fisher, B., Turner, K., Zylstra, M., Brouwer, R., de Groot, R., Farber, S., . . . Balmford, A. (2008). Ecosystem services and economic theory: integration for policy-relevant research. *Ecological Applications, 18,* 2050-2067.

142. OECD. (2003). *Environmentally harmful subsidies: Policy issues and challenges.* Paris: OECD Publishing. Retrieved from http://www.oecdbookshop.org/oecd/display.asp?CID=&LANG=EN&SF1=DI&ST1=5LMQCR2K1R0X

Ecosystem Services Valuation Research and Policy

Although the development of economic incentives to internalize environmental externalities depends on the valuation of those externalities, this is an area where science lags behind policy. The EPA's Science Advisory Board report[143] on the valuation of ecosystem services concluded that "the Agency's value assessments have often focused on those ecosystem services or components for which EPA has concluded that it could relatively easily measure economic benefits, rather than on those services or components that may ultimately be most important to society." Indeed, Federal agencies charged with managing ecosystems tend to report on the value of ecosystem services only where functioning markets exist, such as in agriculture, forestry, and fisheries and, to a lesser extent, water supply. Moreover, they tend ignore in their reporting the externalities in those markets and pay limited attention to them in their decision-making, which fails to reflect the true "balance sheet."

Finding better methods to value the external costs or benefits of actions that affect non-marketed ecosystem services would help ensure that they were appropriately weighted in management decisions.[144] More generally, valuation of non-market ecosystem services would be expected to improve environmental decision-making wherever there are tradeoffs to be made between non-marketed and marketed ecosystem services—as there are between the production of foods, fuels, and fibers, on one hand, and carbon sequestration, watershed protection, biodiversity conservation, and a range of regulating services on the other.[145] Valuation has great potential to inform—and in some cases transform—management and preservation strategies to help sustain the use of our Nation's natural resources.

Advances in valuation methodology over the last two decades make it possible to incorporate ecosystem service valuation as a component of public sector decision-making as a routine matter. For example, cost-based approaches (estimates of damage, replacement, or restoration cost) are now commonly used to estimate the value of regulating services in forests or wetlands.[146] Information on the non-market costs of economic activity is also frequently used to inform the development of incentives to landowners, such as in the well-known Catskills example mentioned above. Elsewhere, China (see Box VII-1) has committed to investments designed to secure those ecosystem services deemed essential to human well-being and is making decisions based on valuation of ecosystem services.

---

143. EPA SAB Committee on Valuing the Protection of Ecological Systems and Services. (2009). *Valuing the protection of ecological systems and services: A report of the EPA Science Advisory Board.* Retrieved from http://yosemite.epa.gov/sab/sabproduct.nsf/F3DB1F5C6EF90EE1852575C500589157/$File/EPA-SAB-09-012-unsigned.pdf

144. Heal, G. M., Barbier, E. B., Boyle, K. J., Covich, A. P., Gloss, S. P., Hershner, C. H., Hoehn, J. P., Pringle, C. M., Polasky, S., Segerson, K. & Shrader-Frechette, K. (2005). *Valuing Ecosystem Services: Toward Better Environmental Decision Making.* Washington, DC: The National Academies Press

145. Rodríguez, J. P., Beard, Jr., T. D., Bennett, E. M., Cumming, G. S., Cork, S., Agard, J., . . . Peterson, G. D. (2006). Trade-offs across space, time, and ecosystem services. *Ecology and Society, 11,* 28. Retrieved from http://www.ecologyandsociety.org/vol11/iss1/art28/

146. Kumar, P. (ed). (2010). *The economics of ecosystems and biodiversity.* London: Earthscan.

Improving decisions and policies that sustain environmental capital requires techniques to quantify the value of ecosystem services as consistently as those used for business accounting. Four advances have made feasible the routine valuation of ecosystem services that is needed:

1. **Decision-makers in the public and private sectors are increasingly aware of the importance of ecosystem services.** The Millennium Ecosystem Assessment (MEA) captured the attention of world leaders, alerting them to the cost society bears when particular ecosystem services are lost. The formation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) is further evidence that decision-makers are persuaded that science now has the capacity to document the loss of ecosystem services and its significance. Indeed, there is a growing recognition that valuing ecosystem services, and making tradeoffs explicit, will better inform decisions and help different stakeholders appreciate the perspectives of others. Indeed, it is striking that private business, including Fortune 500 companies, is beginning to invest in tools for ecosystem service valuation[147] as a means to guide their business decisions and in turn maintain their social license to operate.
2. **The science of biodiversity, functional ecology, and ecosystem services has advanced significantly.** While understanding of the complex relationships between biodiversity and ecological processes will take decades to acquire, the science has improved to the point that it is possible to predict the consequences of many ecosystem changes for ecosystem services. Specifically, it is now possible to predict impacts of land-use and resource-management decisions on a variety of ecosystem processes associated with services.
3. **This improved scientific understanding underpins a growing capability to estimate the economic value of non-marketed ecosystem services.** A critically important development of the last decade is the ability to specify ecological-economic 'production functions' that connect the production of goods and services important for human well-being to an underlying set of ecological functions and processes. In many cases, these functions are being estimated using spatially explicit data, enabling their application to particular landscapes.
4. **Economic valuation methods have matured.** Ecological-economic production functions can be combined with stated-preference and benefit-transfer methods commonly used in economics to yield estimates of the economic impact of changes in biodiversity and other ecosystem components. The capacity to link survey-based and benefit-transfer methods to ecological-economic production functions makes it possible to exploit simultaneous advances in both ecological and economic science.

147. The Dow Chemical Company. (2011). *Dow and The Nature Conservancy Announce Collaboration to Value Nature*. Retrieved from http://www.businesswire.com/news/home/20110124006239/en/Dow-Nature-Conservancy-Announce-Collaboration-Nature

BOX VI-1: CHINA'S ECOSYSTEM SERVICES INVESTMENTS

Ecosystem-service investments being made by China today are far-reaching in their goals, scale, duration, and innovation. Following severe droughts in 1997 and massive flooding in 1998, China decided to invest in excess of 700 billion yuan (ca. U.S. $100 billion) over a decade in national forestry and conservation initiatives:

- The short-term aims of the Natural Forest Conservation Program (NFCP) are to reduce timber harvesting from natural forests and to create alternatives to employment in traditional forest enterprises. The long-term goal (2010-2050) is to restore natural forests and meet domestic demand for timber.
- The Sloping Land Conversion Program (SLCP) focuses on China's greatest cause of soil erosion: farms on steep slopes. The SLCP aims to convert more than 37 million acres of steep-slope cropland to forest and grassland. In addition, more than 42 million acres of land made barren by soil degradation are to be reforested.
- A network of Ecosystem Function Conservation Areas (EFCAs), covering 25 percent of the nation's land area, is being established specifically for ecosystem services provision. The EFCAs will focus conservation in areas with high conservation return on investment. High-impact human activities will be zoned to minimize damage to environmental capital.
- In addition, there are numerous ecosystem service initiatives at sub-national levels, oriented around the provision of drinking water, flood protection and other benefits.

The initiatives have dual goals: to secure critical environmental capital through targeted investments across landscapes and regions, and to alleviate poverty through wealth transfers from coastal provinces to inland regions where many ecosystem services originate. Under these programs, payments to villagers are made in the form of cash, grain subsidies, and tax breaks, in exchange for specific activities required to transition cropland to natural forest, forest plantation, or grassland.

Impacts of these initiatives are being rigorously evaluated to improve their design and efficacy. Evaluation of the NFCP and SLCP shows significant achievement of the biogeophysical goals, with remarkably rapid land conversion in the desired directions. Overall social impacts of the programs are mixed and depend on the details of the financial incentives and property rights.

The current and potential impacts of these ecosystem service investments by China are enormous, for China itself and also for the world. The investments will enhance carbon sequestration and reduce export of dust, which are global public goods. Also, importantly, the lessons learned will be applicable to conservation of natural and associated enhancement of human well-being everywhere.

Sources:

Bennett, M. (2009). *Markets for ecosystem services in China: An exploration of China's "eco-compensation" and other market-based environmental policies.* Washington, DC: Forest Trends

Cao, S., Zhong, B., Yue, H., Zeng, H., & Zeng, J. (2009). Development and testing of a sustainable environmental restoration policy on eradicating the poverty trap in China's Changing County. *Proceedings of the National Academy of Sciences 106,* 10712 - 10716. doi:10.1073/pnas.0900197106

Li, J., Feldman, M., Li, S., & Daily, G.C. (in review). *Rural household income and inequality under payment for ecosystem services: The Sloping Land Conversion Program in Western China.*

Liu, J., Li, S., Ouyang, Z., Tam, C., & Chen, X. (2008). Ecological and socioeconomic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences 105,* 9489 - 9494. doi:10.1073/pnas.0706436105

Xu, J., Yin, R., Li, Z., & Liu, C. (2006). China's ecological rehabilitation: Unprecedented efforts, dramatic impacts, and requisite policies. *Ecological Economics, 57,* 595 - 607. DOI: 10.1016/j.ecolecon.2005.05.008

Zhang, P., Shao, G., Zhao, G., LeMaster, D.C., Parker, G. R., Dunning, J. B., & Li, Q. (2000). China's forest policy for the 21st Century. *Science, 288,* 2135 - 2136. DOI:10.1126/science.288.5474.2135

Progress in Ecosystem Services Valuation

These advances in science, and in policy and business receptivity, are beginning to be reflected in U.S. institutions. Since 2008, the broadly based public-private National Ecosystem Services Partnership[148] and the National Academy of Science has been holding biennial ACES (A Community of Ecosystem Services) workshops. In addition, ecosystem services valuation-related research and policy-related activities are being carried out by some agencies, as discussed in Chapter V. Additional examples, from a wide variety of agencies, are listed in Appendix C. Initiatives of particular note include:

- Establishment of the EPA's National Center for Environmental Economics (NCEE) in 2000.[149]
- Initiation in 2003 of The Conservation Effects Assessment Project (CEAP), in which the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Natural Resources Conservation Service (NRCS), and others collaborate to understand the impacts of conservation practices on the landscape.
- Sponsorship by NIFA and the EPA in 2009 of a $4.5 million competition for "Enhancing Ecosystem Services from Agricultural Lands: Management, Quantification, and Developing Decision Support Tools".
- Leadership by CEQ and OMB in 2010 of a series of interagency conversations on the topic of *Ecosystem Services and Market Policy.* Going forward, the agencies involved in this group will continue to work together on environmental markets (the group name has yet to be formalized).
- Creation of the USDA's Office of Environmental Markets,[150] which as of January 1, 2011 is part of the Office of the Chief Economist.
- Publication of the *Guidelines for Preparing Economic Analyses* by the NCEE in 2011,[151] which is useful for estimating the value of reduced health risks and improved environmental quality.

148. Duke University Nicholas Institute for Environmental Policy Solutions. *Documents and Presentations: Federal Exchanges on Ecosystem Services.* Retrieved from http://nicholasinstitute.duke.edu/ecosystem/nesp/documents-and-presentations

149. U.S. Environmental Protection Agency. *National Center for Environmental Economics.* Retrieved from http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/homepage

150. United States Department of Agriculture. *USDA Office of Environmental Markets.* Retrieved from http://www.fs.fed.us/ecosystemservices/OEM/index.shtml/index.shtml

151. U.S. Environmental Protection Agency. *Guidelines for Preparing Economic Analyses.* (December 2010). Retrieved from http://yosemite.epa.gov/ee/epa/eed.nsf/pages/Guidelines.html

Less progress has been made in using the information generated through valuation for keeping track of the nation's inclusive wealth (wealth including environmental capital). Efforts once undertaken by the U.S. Bureau of Economic Analysis to extend the National Income and Product Accounts (NIPAs) to include environmental capital have been suspended for a number of years. At the same time, however, work has proceeded internationally to develop satellite accounts to complement the U.N. System of National Accounts (UNSNA).[152] In this work, changes in both environmental capital stocks and environmental externalities are addressed via the satellite System of Environmental and Economic Accounts (SEEA).[153,154] These accounts are still under development by the United Nations, the European Commission, the Organization for Economic Cooperation and Development (OECD), the International Monetary Fund (IMF) and the World Bank (which together are the publishers of the SEEA), but they provide a reasonable starting point for the reform of the U.S. NIPAs.

The SEEA includes measures of the effect of environmental change on capital stocks, and comprises four accounts:

- Flow accounts for pollution, energy and materials, recording industry level use of energy and materials as inputs to production along with the generation of pollutants and solid waste;
- Environmental protection and resource management expenditure accounts identifying expenditures incurred by industry, government and households to protect the environment or to manage natural resources (already recorded in the UNSNA);
- Natural resource asset accounts recording changes in traditional natural resource stocks such as land, fish, forest, water and minerals; and
- Valuation of non-market flow and environmentally adjusted aggregates which adjusts aggregates for depletion and degradation costs and defensive expenditures.

152. European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, & World Bank. (2009). *System of National Accounts 2008.* New York, NY. Retrieved from http://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf

153. Lange, G.-M. (2007). Environmental accounting: Introducing the SEEA-2003. *Ecological Economics, 61,* 589-591. doi:10.1016/j.ecolecon.2006.09.003

154. Bartelmus, P. (2007). SEEA-2003: Accounting for sustainable development? *Ecological Economics, 61,* 613-616. doi:10.1016/j.ecolecon.2006.09.008

There are a number of existing proposals to reform the NIPAs, some of which address these issues.[155] It would be advisable for any reforms undertaken by the U.S. Bureau of Economic Analysis to be at least consistent with the SEEA[156] and the way it is currently being developed. What is needed to correct the wealth accounts in particular is both the extension of the set of stocks measured to comprise all relevant sources of wealth, and the inclusion of the non-marketed impacts of asset use on third parties.[157] The most important single addition to make to the set of stocks measured is undoubtedly human capital, which is excluded from both the U.S. NIPAs and the UNSNA. The most important environmental stocks to add are those currently excluded on grounds that they lack sufficiently well-defined property rights. These are not 'ecosystems' as such, but encompass the many public lands, open access resources, and sea areas within the Exclusive Economic Zone that are important components of national wealth, but that do not currently appear in the accounts.[158]

Existing national datasets could be adapted to help track ecosystem service flows and values; current interagency cooperation in the generation of these datasets ought to be extended to include agency and interagency efforts to build estimates of the value of ecosystem services. Some of the relevant datasets are:

- Soil and water quality, soil erosion, and farm surveys
- National Land Cover Dataset (NLCD)
- National Hydrography Dataset (NHD)
- National Wetlands Inventory (NWI)
- USFS Forest Inventory and Analysis data (FIA)
- Gap Analysis Program (GAP)
- Digital elevation models and geologic maps

Data should be spatially explicit wherever possible, and Federal agencies responsible for public lands and environmental quality should take advantage of private and nongovernmental partners to provide detailed data that are not maintained by Federal agencies, as well as the informatics capabilities of EcoINFORMA (see Chapter VIII).

---

155. Jorgenson, D.W. & Landefeld, J.S. (2006). Blueprint for expanded and integrated U.S. accounts: review, assessment and next steps. *A New Architecture for the U.S. National Accounts* (ed. By D.W. Jorgenson, J.S. Landefeld, & W.D. Nordhaus), pp 13-112. Chicago, IL: Chicago University Press

156. United Nations Statistics Division. (2003). *Handbook of National Accounting Integrated Environmental and Economic Accounting 2003*. Retrieved from http://millenniumindicators.un.org/unsd/envaccounting/seea.asp

157. Although a majority of countries compile one or more such accounts at the national level, both quality and coverage are highly variable. A separate initiative by the World Bank has led to the development of a new indicator called "adjusted net savings". This adjusts the measure of savings recorded in the national income accounts to reflect depreciation of stocks of natural assets. Even though it is far from complete, it may be the best available indicator of changes in the value of ecosystem services. Following up on the TEEB initiative, the World Bank is establishing the Global Partnership for Ecosystems and Ecosystem Services Valuation and Wealth Accounting, which is an initiative designed to demonstrate the integration of ecosystem services into national accounting.

158. Nordhaus, W.D. (2006). Principles of national accounting for non-market accounts. *A New Architecture for the U.S. National Accounts* (ed. By D.W. Jorgenson, J.S. Landefeld, & W.D. Nordhaus), pp 13-112. Chicago, IL: Chicago University Press

Recommendations

- **Current agency and interagency efforts to value ecosystem services should be expanded and built upon to generate new knowledge about the impacts on ecosystem services (in both physical and value terms) of activities taking place on both public and private lands, watersheds, and coastlines.**
  - Federal agencies with responsibility for biodiversity, ecosystems, and ecosystem services should take into account information on the value of ecosystem services in all major planning and management decisions. In particular, they should develop incentive mechanisms to encourage beneficial uses of land and resources and to discourage harmful uses.
  - If ecosystem services can be monetized, new entrepreneurial opportunities for private business will arise. The effect will be both to "green the economy" and to provide opportunities for only a modicum of effort.
- **Agencies that manage the impacts of economic activity on biodiversity and ecosystem services should consider using ecosystem valuation information in the following ways:**
  - Where assets are held privately, and where people's use of those assets generates externalities, use the range of economic instruments currently available to confront resource users with the social cost of their actions. Valuation can be employed to estimate social cost.
  - Where assets are held in public trust, and where these assets generate services whose benefits are privately capturable, use instruments such as user charges, access fees to regulate access. Valuation can be helpful in determining the private benefit, and so the appropriate level of such charges.
  - Where assets are held privately, but generate services whose benefits are public goods, use systems of PES to encourage the provision of social benefits. Valuation can determine the extent of the social benefit involved, and hence the optimal level of payments to be made.
  - Where market-based instruments developed for other purposes have negative environmental effects, as many agricultural subsidies do, remove the harmful incentive. Valuation can help determine the social consequences of existing incentives.
- **The U.S. Bureau of Economic Analysis should renew efforts to track ecosystem service flows and values using satellite-based remote sensing of natural resources to record changes in the quantity and value of ecosystem services provided by terrestrial and marine ecosystems.**

VIII. Using Informatics to Support the Sustainability Agenda

As noted in a recent PCAST report,[159] "… the advancement and application of [networking and information technology is] squarely at the center of our Nation's ability to … address essentially all of our challenges." Policy-makers who deal with biodiversity and ecosystems issues have a pressing need to be able to make scientifically and socially informed decisions in order to ensure the continuation of essential human services from natural systems. To provide the information these policy-makers need in forms they can use, the capabilities of **informatics** (for concise definitions of terms, see Box VIII-1) must be brought into play, including:

- modeling and simulation decision-support software that can incorporate the many kinds of data, and the massive amounts of data, needed to build predictive scenarios that take into account the complexity of natural systems and the impacts and competing demands of human systems; and
- the underlying data and information infrastructures that mobilize data for use in these simulations and models.

An example of the application of a software tool of the type described above is the analysis conducted by E. Nelson and coworkers of the Natural Capital Project.[160] In this study, the authors show how three plausible scenarios for land-use and land-cover change in the Willamette Basin in Oregon between 1990 and 2050 would differently affect a range of ecosystem services (water quality, storm mitigation, carbon sequestration, and the conservation of soil and biodiversity), and the value of marketed commodities (agricultural products, timber harvest, rural residential housing). They used the software tool InVEST—Integrated Valuation of Ecosystem Services and Tradeoffs,[161,162]—one among several tools (see Box VIII-2) that can model delivery, distribution, and economic value of ecosystem services into the future, helping users visualize the impacts of potential decisions and identify tradeoffs and compatibilities between environmental, economic, and social benefits.

159. PCAST. (2010). *Designing a digital future: Federally funded research and development in networking and information technology*. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf

160. Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., . . . Shaw, M. R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment,* 7, 4–11. doi:10.1890/080023

161. Nelson, E. J., & Daily, G. C. (2010). Modeling ecosystem services in terrestrial systems. *F1000 Biology Reports,* 2, 53 et seq. doi: 10.3410/B2-53. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2990460/

162. Natural Capital Project. *InVEST: Integrated Valuation of Ecosystem Services and Tradeoffs.* Retrieved from http://www.naturalcapitalproject.org/InVEST.html

BOX VIII-1: SOME BASIC CONCEPTS

Informatics. A developing field that encompasses human-computer interaction, information science, information technology, and computer science, as applied to various information domains such as medical informatics, biological informatics (bioinformatics), chemical informatics (chemoinformatics), geographic informatics (geoinformatics), and biodiversity and ecosystem informatics (ecoinformatics). Informatics involves science and technology that deal with the structure and character of information; its capture, classification, and qualification; and its storage, processing, visual representation, maintenance, and dissemination, including the infrastructure necessary to secure optimal use of the information.

Cloud-Based Computing. Computing that is not dependent on the user and the computer server in use being in the same place, because the computing services are provided dynamically over the internet. This frequently takes the form of web-based tools or applications that a user can access and use through a web browser as if they were installed on his or her own computer. Computer servers that are "in the cloud" can also provide capacity for scalable and sustainable information storage and accessibility.

Application Programming Interface (API). A set of rules and specifications that allows software programs to interact, analogous to the way that a user interface facilitates interaction between humans and computers.

Data Accessibility. The software and activities related to storage and retrieval of information.

Data Curation. The care, maintenance, updating, and quality control of datasets that allows for continued data accessibility, usefulness, and preservation over time.

Data Integration. Datasets from multiple sources are combined together to provide a unified view or in a single analysis. Integration provides the means to simultaneously visualize or statistically account for many factors that are part of a complex issue or question. Locating and assembling the datasets can often be the most time-consuming part of the analysis.

Data Interoperability. Datasets from many sources are delivered to the user via a single point of access. When the informatics tools to do this are adequately implemented, the datasets that can be tapped through that access point are said to be interoperable. Data interoperability can greatly enhance and facilitate data integration, by greatly reducing the time required to locate and assemble datasets.

Data Object. Any representation of structured data that can be manipulated by software commands.

Data Publication. The act of making data available to external users. That is, making data accessible via the internet, in contrast to allowing use only by an individual within an organization or institution.

Data Vocabulary. An index or set of tags used for subsequent information retrieval that is formally organized so that existing relationships between concepts are made explicit. Also called a *thesaurus*.

Open Government Data. Data that are gathered, assembled, and published by agencies, to which the public has equal access (see Boxes VIII-3, VIII-4).

Metadata. Most generally, metadata are data about data (or datasets). Metadata provide information about one or more aspects of the data, which may be grouped into archival metadata such as author of the data, the time and date of data creation or assembly, and data ownership and/or custodianship; and contextual metadata such as the purpose for which the data were collected, the standards used in data collection, and tags that indicate how information products derived from the data may be found.

Universally Unique Identifiers for Data Objects. The application of some form of "name tag" to data objects that identifies each one as a unique entity within the universe of all data objects. An example is the Universally Unique Identifier (UUID) that has been standardized by the Open Software Foundation as part of the Distributed Computing Environment.

BOX VIII-2: EXEMPLAR SOFTWARE TOOLS FOR BIODIVERSITY AND ECOSYSTEMS DECISIONS

Software tools that integrate diverse sources of biodiversity and ecosystems data for various purposes already exist, both in the proprietary arena and as open source. Examples of these include:

- **The USGS Gap Analysis Program (GAP) Online Tool** (http://www.gapserve.ncsu.edu/swgap/swgap/) provides habitat models for species of concern at the state and Federal level based on multiple sources of monitoring and remote sense data. These GIS models can be accessed by any user and overlain on included maps of management areas or congressional districts.

- **The Protected Areas Database of the United States (PAD-US) Viewer** (http://gap.uidaho.edu:8081/padus/padus2.do) utilizes the GAP land cover data in an online tool in which users can select various overlays (political jurisdictions, management organization, conservation status) and base map layers (satellite, street, topographic).

- **FracTracker** (http://www.fractracker.org/p/how-fractracker-works.html) is a web-based public participation geographic information system that uses volunteered geographic information, allowing users to visualize information and map geo-located data related to gas extraction activities.

- **EcoMetrix** (Parametrix, Inc., Auburn, WA, USA; http://www.parametrix.com/cap/nat/_ecosystems_ecometrix.html) is one of a growing number of propriety software systems that are designed to help local governments design and implement ecosystem service conservation programs, including payment for ecosystem service programs.

- **Google Earth Engine's Forest Monitoring Application** (http://earthengine.googlelabs.com/) tracks deforestation in real time at the global scale by utilizing massive-scale computing approaches to store, analyze and disseminate results to governments and the public. It will facilitate tracking of compliance with incentives for tropical countries to preserve rainforests under REDD (Reducing Emissions from Deforestation in Developing Countries; http://www.un-redd.org/).

- **Envision** (formerly **EvoLand**; Oregon State University; http://envision.bioe.orst.edu/) is a GIS-based tool that combines spatially-explicit alternative scenario strategies, landscape-change models, and models of ecological, social, and economic services to simulate land-use change and provide information about resulting effects on valued products of the landscape.

- **Artificial Intelligence for Ecosystem Services (AIRES)** (http://www.ariesonline.org/)—uses a benefits-transfer approach to estimate the biophysical provision of multiple ecosystem services across a landscape, translate this provision into maps of service use (who and where people are benefiting from service provision) and monetary value (the value that people receive from the use of the service), and predicts trends in service provision and values.

Although the capabilities exercised in the Natural Capital Project study are impressive, it is imperative to push for prediction and simulation tools with even greater capabilities (see Chapter VI), and to build infrastructure and tools that enable others to replicate such analyses in other settings, as noted in a very recent community-wide workshop report.[163] In order to make natural-resource decisions more effective,

163. National Council for Science and the Environment. (2011). *Creating a ten-year, global, integrated, multi-dimensional biodiversity initiative: Results of a workshop*. Retrieved from http://www.ncseonline.org/biodiversity.

efficient, and defensible, policy-makers need to analyze tradeoffs between economic development and provision of ecosystem services. They also need to be able to plan for mitigating the impact of crisis events. They need higher resolution data and analyses than is now possible, along with evolution of simulation and forecasting capabilities. Particularly important are modeling methods that can address multiple and non-linear relationships among different ecosystem services and other variables in the models.[164] The necessary tools must be able to manipulate massive amounts of disparate data and be capable of generating multiple predictive scenarios to test the assumptions and preferences of different stakeholder groups.

In short, decision-makers in the biodiversity and ecosystems arena need an ecological equivalent of the flight simulation tools such as those used by NASA, the U.S. Armed Forces, and commercial airlines to train astronauts or pilots to find optimum flight paths as well as to deal with crises. Those digital models of the real world incorporate dozens of data types so that they can mimic reality as closely as possible. "Ecological flight simulator" models must also incorporate vast amounts of data representing multiple data types. Informatics challenges presented within the information domains relevant to ecosystems that are even greater than those involved in simulating flight conditions.

The biodiversity and ecosystem data and information domains are particularly challenging because they are extremely heterogeneous, coming from multiple kinds of monitoring platforms both on the ground and from remote sensing, and based on continuing biodiversity surveying and exploration that began three centuries ago. This temporal, spatial, and methodological heterogeneity leads to a depth and richness in biodiversity and ecosystems data not found in other fields. It also makes dataset interoperability a problem that is at the same time particularly challenging and highly important to solve. As well, of particular importance to informed analysis, as is clear from other recommendations (see Chapter VI), is to be able to integrate data from the human dimension, especially social, economic, and valuation data,[165] and to enable "vertical" integration (see Chapter VII) of ground-based and space-based observations.

Delivery of high-quality datasets that are fit for the use to which they will be put and that are interoperable with the many other datasets that are also needed, along with the complexities of software development, constitute an informatics challenge that cannot be met by a single system or entity.[166] Instead, the Working Group believes that what is needed is an informatics structure with three categories of capabilities that should be thought of as "layers" because the second is dependent upon the first, and the third depends on the second:

1. **data access and preservation;**
2. **data integration and interoperability; and**
3. **data use in decision-support tools.**

164. Bennett, E. M., Peterson, G. D., & Gordon, L. J. (2009). Understanding relationships among multiple ecosystem services. *Ecology Letters, 12,* 1394–1404. doi: 10.1111/j.1461-0248.2009.01387.x

165. Chan, K. M. A., Shaw, M. R., Cameron, D. R., Underwood, E. C., Daily, G.C. (2006). Conservation planning for ecosystem services. *PLoS Biol., 4,* art. no. e379.

166. Science Magazine Special Section. (2011). Dealing with Data. *Science, 331,* 692-729. Retrieved from http://www.sciencemag.org/site/special/data.

The components and structure of each layer are discussed in more detail below, under the appropriate heading. Government has an important role in building this informatics structure, but it is not the only player—academia, non-governmental organizations, the public, and the private sector also have important roles to play and contributions to make—although there is a clear need for an interagency entity to coordinate, facilitate, and guide development of these informatics infrastructural layers. The recommendations that close this chapter of the report address these findings.

Data Access and Preservation

This first layer of capabilities ensures that data can easily be accessed and interacted with by both humans and other computer programs, and that the data are preserved over time. It must also guarantee that appropriate metadata, which are necessary for further use and re-use, are also encoded with the data. Metadata must be separately searchable but ultimately inseparably linked to the data they describe, so that as those data are subdivided or transformed, data descriptors flow together with the data through those operations. Functions and processes at this fundamental level include but are not limited to:

- persistent, secure, and scalable storage of machine-readable data that is preserved into perpetuity;
- publishing of data and metadata into one or more recognized repositories, whether those repositories are locally managed or in "the cloud," that are accessible to all citizens in formats that promote maximum usability;
- data-object identification so that each datum can be discovered, accessed, annotated and tracked; and
- contextual and archival descriptions of data (i.e., metadata) that describe the conservation, use, and provenance of data objects.

Members of this Working Group believe that, for government data, providing these fundamental services is the responsibility of the government agencies that have generated or will generate the data, working separately or in concert (the latter would be more cost-effective). Agencies need to be appropriately resourced to coordinate or combine such services across agencies to:

- assure that incentives are in place to support the core functions and processes described above, particularly data description (i.e., metadata generation);
- achieve cost-effectiveness through efficiencies of data management;
- facilitate data publication, according to government-wide best practices, into well-managed and curated repositories; and
- coordinate with providers of the same types of functions in other sectors (academic, non-governmental, etc.), regarding standards for data and metadata, and establishment of data-object identification. This is because the data and information needed come from all of these sectors, not just government agencies.

Although progress is being made to preserve and provide access to government biodiversity and ecosystem data, agencies have yet to fully demonstrate the willingness to meet all the tenets of Open Government[167] data (see Box VIII-3). Creating a well-informed public is a core value of representative government. An essential building block for creating an informed public is to guarantee that all citizens have equal access to data created and published by their government. Open Government data fits within the larger Executive Office of the President's Open Government directive[168] that has been advocated by many individuals and groups.[169,170,171,172,173] Datasets relevant to biodiversity and ecosystems are currently stored on thousands of individual computers, scattered across many different agencies, in a variety of different formats[174] and are not widely accessible.[175] This inefficiency leads to both duplication of effort (and therefore expense) among agencies, as well as difficulty for stakeholders to discover essential data. It is of the utmost importance that the Administration act immediately and consistently to ensure that Federal agency datasets adhere to the principles intended by the Open Government directive, and that these and the data that result from federally-funded research be made openly available in formats that allow interoperability as rapidly as can possibly be achieved. Box VIII-4 highlights the advantages of publishing data according to Open Government data standards.

Recent technological advances enable easy publishing of structured data sets, while allowing owners of the data to maintain control as the data change.[176,177] Such systems are currently being prototyped for biodiversity data-sharing missions. These services are scalable to large amounts of data and enable various degrees of data manipulation and visualization. Key benefits of such services include a mechanism for preserving data over time, and the means to easily set or reset levels of access to published data, ranging from sharing with a small set of collaborators to the public at large. Furthermore, if permissions are appropriately set, the datasets will be crawled by search engines; hence, relevant data can appear in response to the multitude of queries posed to these engines. Some of these publishing-environment services offer measurement facilities to track the viewing and usage of the data, giving an indication of their impact on society.

---

167. OMB. (2009). *Open government directive* (M10-06). Retrieved from http://www.whitehouse.gov/open/documents/open-government-directive

168. OMB. (2009). *Open government directive* (M10-06). Retrieved from http://www.whitehouse.gov/open/documents/open-government-directive

169. Gorman, S. (2009). Information as a public good. *Intergovernmental Solutions Newsletter: Transparency and Open Government.* USA: GSA Office of Citizen Services and Communications.

170. Berners-Lee, T. (2009). *Putting government data online.* Retrieved from http://www.w3.org/DesignIssues/GovData

171. Tauberer, J. (2010). *Open data is civic capital: Best practices for "Open Government Data".* Retreived from http://razor.occams.info/pubdocs/opendataciviccapital.html

172. Sunlight Foundation. (2010, August). *Ten principles for opening up government information.* Retrieved from http://sunlightfoundation.com/policy/documents/ten-open-data-principles/

173. Open Government Working Group (OGWG). (2007). *Eight principles of open government data.* Retrieved from http://www.opengovdata.org/home/8principles

174. Pennisi, E. (2005). Boom in digital collections makes a muddle of management. *Science, 308,* 187–189. doi: 10.1126/science.308.5719.187

175. Interagency workshop on Integrating Biodiversity and Ecosystems information systems. (2010). *Interagency workshop on Integrating Biodiversity and Ecosystems information systems report: Transparency, participation & collaboration.* Retrieved from: http://www.nbii.gov/homepage/about/20100628_FINAL_IntagncyWkshpRpt.pdf

176. Constable, H., Guralnick, R. P., Wieczorek, J., Spencer, C., Peterson, A. T., & the VertNet Steering Committee. (2010). VertNet: A new model for biodiversity data sharing. *PLoS Biology, 8*(2), art. no. e1000309. doi:10.1371/journal.pbio.1000309

177. Gonzalez, H., Halevy, A., Jensen, C., Langen, A., Madhavan, J., Shapley R., & Shen, W. (2010). Google fusion tables: Web-centereddata management and collaboration. *SIGMOD Conference 2010,* 1061-1066.

BOX VIII-3: OPEN GOVERNMENT DATA

Two provisions of the Open Government directive from the executive branch relate to data explicitly:

Provision 1: Data publication means that there exist mechanisms to:

- support obtaining the names and metadata of all existing data sources;
- support a search interface that returns all the data sources that are relevant to a particular keyword query; and
- enable download of any data source with its accompanying metadata in a format such as standard format text file, so that it can be further processed by applications.

As an example, with the above functionality, an innovative third party can build a search engine over the published data. Data tables within a PDF document or embedded in an HTML file do not meet these requirements for true data publication.

Provision 2: Data improvement is an umbrella for many activities, but important among these is the generation of adequate metadata, as has been recognized in Executive Order 12906, that established the National Spatial Data Infrastructure and the Federal Geographic Data Committee. Several types of metadata are needed. These describe the data with regard to:

- ownership and/or stewardship;
- format (how the data record is organized and what it contains);
- context (how and why the data were gathered);
- subject or topic and type of the resource; and
- temporal and spatial coverage or topic.

Source: OMB. (2009, December). *Open government directive* (M10-06). Retrieved from http://www.whitehouse.gov/open/documents/open-government-directive

Publishing and providing the means to integrate very diverse streams of environmental data, information, and knowledge is a grand societal challenge in this knowledge century.[178] To meet this challenge, adequate resources for data curation and publishing should be immediately made available so that the capacities outlined above can be achieved and the mandates of Open Government met. In-depth consideration should be given to cloud-based computing to accomplish data publication cost-effectively[179, 180] while at the same time enhancing discovery and interoperability. Publishing to a "single" cloud-based platform would mean that:

178. National Research Council. (2001). *Grand challenges in environmental sciences.* Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=9975

179. Kepes, B. (2010). *Moving your infrastructure to the cloud: How to maximize benefits and avoid pitfalls.* (White paper). Retrieved from http://www.rackspace.com/hosting_knowledge/whitepaper/moving-your-infrastructure-to-the-cloud-how-to-maximize-benefits-and-avoid-pitfalls/

180. Reese, G. (2008). The economics of cloud computing. *O'Reilly Community.* Retrieved from http://broadcast.oreilly.com/2008/10/the-economics-of-cloud-c.html

- data administration would be much simpler, which would lessen the number of Federal staff that must be employed;
- redundancy of unsynchronized dataset copies would be reduced, because multiple users could access the same copy, but, at the same time, data preservation and security would be increased through data-replication services;
- computing speed and efficiency would be enhanced by using many computer processes simultaneously, but only as needed (that is, as the requirements of the problem increase or decrease, the amount of computing capacity allocated to that problem increases or decreases proportionately);
- the need to build systems that have to address multiple, different database systems would be eliminated—thus reducing software development costs; and
- many new services or tools useful for decision-making can be easily attached to the single platform, which means that those tools that are developed would be used more widely.

These resources must support not only data capture and publication into repositories (which could be cloud-based), but also development of and adherence to appropriate standards; use of universally unique, persistent identifiers[181] (UUIDs; see Box VIII-1) for identifying, tagging, and tracking data objects and deployment of evolving best practices for data management. This Working Group strongly recommends that the most efficient way to use these funds is to establish, or enhance an existing, interagency entity or initiative, that will have the mandate to carry out these activities.

The current capabilities of Data.gov are an important first step toward the system for publication of data envisioned here. However, it is only the first step. The current Data.gov does not have the flexibility and integrative capacities to support a flourishing environment of access support (specialized search engines), user portals, and applications for analysis and decision support. In particular, it does not allow third parties to easily and automatically download all data sets. The capabilities of Data.gov must either be significantly enhanced or the concept should be re-implemented so that accessibility and interoperability are maximized. As Data.gov is moved into "the cloud," the capabilities we have indicated here should be incorporated.

It is also clear that the directive to agencies to publish data to Data.gov is not being followed with alacrity. Of the 55 national monitoring programs listed in Appendix D, the resulting datasets from only 11 are in Data.gov; only 4 more provide minimal to partial availability. Some agencies' entries in Data.gov only link to the agencies' own data centers or websites; their datasets are not directly accessible via Data.gov. And, although it appears that thousands of datasets have been published to Data.gov, the actual numbers in the repository are much lower, because different versions of the same datasets lead to artificial inflation of dataset numbers.

181. Richards, K., White, R., Nicolson, N., & Pyle, R. (2011). *A Beginner's Guide to Persistent Identifiers*, version 1.0 (released 9 Feb 2011). Copenhagen, Denmark: Global Biodiversity Information Facility. Retrieved from http://links.gbif.org/persistent_identifiers_guide_en_v1.pdf

BOX VIII-4: ADVANTAGES OF OPEN DATA PUBLISHING

A number of public data resources maintained by the U.S. Government have helped to spur innovation. Among these, GenBank and related molecular databases maintained by the National Center for Biological Informatics (NCBI) are among the most successful.

The rate of usage is one measure of effectiveness. Each day, approximately 1.7 million users access these public repositories of molecular biological data, downloading approximately 10 terabytes of data. This amount is about equivalent to the entire contents of the Library of Congress.

All the information in these resources has been contributed by the international scientific community. GenBank is able to track over 148 billion DNA sequences and related molecular information; it houses over 900 complete genomes, including the human genome, and partial genomes for more than 95,000 other species.

NCBI staff vet the submissions to ensure quality, maintain the computer systems that provide worldwide access, and develop search engines and other tools that facilitate usage. For the scientist, the GenBank approach to data management offers several advantages. The delay in accessing the latest information is minimal, and the data are free to anyone who wishes to use them.

Another measure of success is the wide range of significant applications this valuable data resource makes possible. Already it is used in the development of new treatments for diseases and developing new biotech products, as well as other medical, pharmacological, agricultural, and basic biological research. Future, unpredictable uses may easily match or exceed what has already been done.

Already, an entire industry has been spawned around GenBank—an industry that has created a constellation of tools for searching, visualizing, and analyzing the data. Most of these tools were developed using non-government funding sources.

Much like the evolution of other government funded data services, including NOAA's weather data, the topographic and geologic maps of the USGS, and the SEC's EDGAR system, GenBank is a clear demonstration that the open publishing of data can help to spur innovation both within the government and outside of it.

The Working Group is also concerned, in connection with data availability and accessibility, about the tendency of agencies to institute the same security regimes on scientific data as they do on Personally Identifiable Information (PII).[182] Viewed from the perspective of an agency's information office, this is understandable; but when viewed from the perspective of the agency's scientists, it can be detrimental to the conduct of research and to collaboration with academic- and private-sector researchers. Strong measures should be put in place to recognize the special status of scientific data and the need for it to flow openly and freely.

182. Interagency Workshop on Integrating Biodiversity and Ecosystems information systems. (2010). *Interagency Workshop on Integrating Biodiversity and Ecosystems Information Systems Report: Transparency, Participation & Collaboration*. Retrieved from: http://tinyurl.com/4l9yqr4

Data Integration and Interoperability

Even if data are published, discoverable, and assured of preservation over time, one of the major impediments to cross-agency and cross-domain data integration is the lack of clear linkages and connectivity among datasets. Establishing linkages and connectivity in order to render the data interoperable is the function of the second layer. This layer is enabled by proper description of data (e.g. metadata) that, among other important features, facilitates linking between items in different data sets by indicating, for example, which fields within the data records of the different datasets carry the same type of information.

It is the consensus of the Working Group that existing mechanisms that achieve interoperability need to be enhanced and expanded, and new mechanisms developed, as rapidly as possible. These mechanisms include (but are not limited to):

- accessibility and connectivity to the data through application program interfaces (APIs) so that it is easy for users and other computer applications to retrieve these data;
- common vocabularies and thesauri to maximize standardized results returns;
- maps of the differing locations of similar information as found in different database implementations or data standards (called "crosswalks") to promote automated exchanges of similar types of data (for example, data generated from different remote-sensing platforms);
- validation and interpretation services to check incoming data and provide standardized interpreted fields from non-standard input data; and
- shared transmission protocols and synchronization processes that allow data updates, annotations, and edits to be made across data-publishing systems.

The task of building and adopting common mechanisms for interoperability is not unique to the government. Rather, it belongs to the entire community of data generators, providers, and users. However, to build this layer of the platform so that it serves all, everyone must participate in the development of the necessary standards and protocols. And, even though these are community-wide activities, the community needs coordination to assure that all voices are heard during the development of the parts of the system that must be held in common. Coordination is also needed to bridge between government agencies that hold and use biodiversity and ecosystems data and other parts of the community that do the same. This would be to the advantage of both government agencies and the public. Essential activities of a coordinating entity of this type include development of:

- application programming interfaces (APIs) and web-based services to maximize data interoperability;
- standardization of fields and data vocabularies for essential attributes such geospatial coordinates, time stamps, taxonomy, and ecosystem services;
- services that can validate and provide standardized interpretations of incoming data; [183] and
- mechanisms for community-based data improvements, annotations, and additions.

183. For example, the Integrated Taxonomic Information Service comparison tool: http://www.itis.gov/taxmatch_ftp.html

Data Use in Decision-support Tools

With the data accessibility layer and the data interoperability layer of the informatics structure in place, any number of institutions or organizations—government, private sector, academic—can build the tools and applications of the data use layer. Such tools, including the predictive models described in Chapter VII, would extract knowledge from the data to support research, policy analysis, decision-making, and other uses (many of which may be quite removed from the purposes for which the data were originally gathered). This diversity of uses greatly increases the return on the investment made in building a smart informatics foundation.

InVEST, the software tools listed in Box VIII-2, or the new *U.S. AID Predict Healthmap* online tool[184] for predicting the spread of animal-borne diseases, are just the merest beginning on what is possible for talented biologists and software engineers to design and build. With better foundational layers in place, the potential for developing sophisticated "ecological flight simulators" is unlimited. In turn, this potential can inspire innovative software companies to create job positions for designers who will turn out products that will facilitate local, state, regional, and national decision-making for biodiversity preservation and ecosystem sustainability and enable connections between the ecological informatics structures of this Nation and those of the rest of the world.

Informatics Coordination and Facilitation

Progress toward the three-layered informatics structure envisioned here will be haphazard and slow without coordination and facilitation by a focal entity of some sort. Yet, all of the recommendations of Chapters II-VII, above, are dependent on data availability, management, and interoperability across scientific disciplines, agencies, and sectors. Thus, there is a demonstrable need for some unit of the Federal government to be charged with the responsibility of building the interagency cooperative projects and collaborations, as well as promoting the public-private partnerships, that are needed to develop the informatics functionalities that are described above.

We propose that this entity be called EcoINFORMA—Ecoinformatics-based Open Resources and Machine Accessibility. EcoINFORMA could be designed *de novo*, or an existing entity could be elevated in prominence, resources, authority, and function to achieve the goals laid out in this report. However EcoINFORMA is constituted, all of the agencies listed in Table III-1 must have a part in it. The savings in time and funds through the elimination of duplication of effort among the many agencies will serve all of them: business, industry, and state and local governments, as well as the public and the research community.

This Working Group believes the need for the functions we describe cannot be met by Data.gov, an initiative that is focused on dataset availability. EcoINFORMA is intended to be an essential **informatics** activity, and it must be organized at the Departmental or NSTC level rather than the bureau level, must be given that mandate, and must have the funding necessary to work with all other relevant agencies to assure that the challenges of interoperability and coordination are met.

184. USAID PREDICT. *HealthMap.* Retrieved from http://healthmap.org/predict/

This Working Group suggests that EcoINFORMA could come on-line more rapidly if the existing National Biological Information Infrastructure (NBII), currently situated within the Core Science Systems directorate of the U.S. Geological Survey, were to form the initial core of EcoINFORMA. However, EcoINFORMA should be instituted at a level above individual bureaus rather than within a single one, and have advisory authority to all relevant offices and entities within the Executive Branch, regardless of the agency to which they belong.

The NBII has, since 1994, been developing metadata and data vocabularies (thesauri); supplying training in metadata generation to other agencies; providing search engines and indexing specific to the biodiversity and ecosystems information domain; as well as developing web access to software tools of various types and providing topic-focused portals to biodiversity and ecosystem information. Its staff have been instrumental in the development of several of the standards for biodiversity and ecosystems data and metadata currently in use globally. They are participating at present in the creation of international standards for, among other things, image indexing and long-term dataset curation. NBII also has attempted to redress the absence of biodiversity and ecosystems data on Data.gov; it provides access to datasets from half of the 40 monitoring programs (Appendix D) that are neither represented on Data.gov nor made available directly by the owner agencies. An earlier PCAST[185] recommended that a "next generation" NBII be empowered to carry out much the same functions called for by the present Working Group in this Report. Ever since, NBII has been striving to meet environmental policy needs with the very best scientific data, methods, and tools, using the *Teaming with Life* report as a guidance document. However, NBII has been insufficiently funded, prevented from achieving interagency prominence, and not given the clear mandate described here; in short, it has been prevented from providing the very services that PCAST deemed essential in 1998 and that we iterate now.

The agencies listed in Table III-1 must be directed to collaborate with EcoINFORMA and be facilitated and coordinated by it as part of the effort led by the "interagency public access committee" (America COMPETES Reauthorization Act of 2010, Section 103) to publish their biodiversity and ecosystems data in a manner that will enable discovery and interoperability. In addition, EcoINFORMA must also work with the Bureau of Economic Analysis and other sources of socio-economic data; the Earth Observing System to create means to integrate data across spatial, temporal, and social scales and across information domains; and with all the many Federal and other governmental agencies, bureaus, and offices that generate data in the biodiversity and ecosystems information domain and the information domains that intersect with it.

EcoINFORMA needs to have the following core competencies:

- **Capability to**
  - manage a system that serves hundreds of queries per second on its data;
  - log the accesses and analyze the frequency of the requests to different data sets and the kinds of queries that it is receiving; and
  - channel requests for additional data sets and additional metadata to the appropriate data owners.

185. PCAST. (1998). *Teaming with life: Investing in science to understand and use America's living capital.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-teamingwithlife.pdf

- **Capacity to**
  - assist data generators / owners with metadata generation;
  - participate in the development of standards for data and metadata across the environmental sciences community both within government and across other sectors;
  - implement protocols for data exchange and interoperability; and
  - coordinate its activities with other entities, efforts, and initiatives in informatics across sectors, as well as infra- and supra-nationally.
- **Authority to**
  - enforce deadlines on publishing data; and
  - coordinate and implement plans for adoption of evolving standards and protocols.

Federal agencies need to develop not just data but also mechanisms and tools that support converting massive amounts of data into summaries that have the most use in downstream ecological assessments and in the creation of information and knowledge. These developments need to be accomplished in partnership among the government and all other sectors. It is the direct observation of members of this Working Group that when an agency attempts to develop complex tools "in house," the result is almost always disappointing. Tool-development of this sort can greatly benefit from the creativity and specialized expertise that the private and academic sectors possess. Thus, EcoINFORMA should coordinate among the government, academic, and private sectors in order to continue development of the kinds of "ecological flight simulation" tools that are already beginning to be developed, as described in Box VIII-2.

Informatics is inherently a cooperative activity. Just as all drivers in the western hemisphere adhere to the community standard of driving on the right-hand side of the road, more progress and fewer crashes will be achieved in informatics if community standards are agreed upon and followed. The standard of driving on the right isn't limited by national boundaries and neither should the standards used within informatics be national only. Standards and protocols for the basic features of the Internet are global; it is only wise to carry this universality through to the standards and protocols for functions that are built on that foundation. Development of global community standards is greatly facilitated and sped up if there is a coordinating body with the capacity to run workshops and derive results from consensuses achieved. EcoINFORMA must interact organizationally with international informatics entities such as GBIF and GEO BON, participating with them in the development of standards for data and metadata, internet and software protocols, data vocabularies, etc.

Biodiversity and ecosystem informatics has suffered, to date, from a bit of provinciality—it would benefit greatly from the lessons learned, approaches, and deliberations that have gone on in, for example, the medical field,[186] adopting and adapting those developments as appropriate. At the same time, biodiversity and ecosystem informatics has and is conquering degrees of complexity in data that are not found in other information domains, and thus has much to contribute to wider considerations of information

186. PCAST. (2010). *Realizing the hull potential of health information technology to improve healthcare for Americans: The path forward.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-health-it-report.pdf

technology research and development.[187] Thus, EcoINFORMA should also represent the biodiversity and ecosystems community in higher level discussions of national information policy, particularly in deliberations concerning National Information Technology Research and Development (NITRD) and the "interagency public access committee" that is to be established under the NSTC under the authority of the America COMPETES Reauthorization Act of 2010, Title I, Section 103.

Recommendations

- **The OMB should enforce existing requirements that Federal agencies publish data related to biodiversity preservation and ecosystem services within one year of collection.**
  - Enforcement requires no new standards, and can be achieved through application of language specified in the America COMPETES Act and the Open Government directive.
- **A facilitating and coordinating entity should be established by OSTP and NSTC to develop informatics capabilities that will serve all biodiversity and ecosystems-relevant agencies, national and regional assessments, and other integrative activities.**
  - This entity or initiative will be called EcoINFORMA—Ecoinformatics-based Open Resources and Machine Accessibility.
  - To reduce current duplication of effort and expense and increase productivity, agencies will work with EcoINFORMA to assure that their data relevant to biodiversity and ecosystems, as well as the socio-economic and geophysical data discussed in this report, are published in machine-readable, interoperable format to facilitate research and to support policy- and decision-making.
  - EcoINFORMA will also serve a bridging function among the Federal government, state and local governments, and other sectors of society, and provide a platform useful to all.
- **EcoINFORMA should seek out and encourage partnerships with the private and academic sectors to maximize financial savings and develop innovative tools for data integration, analysis, visualization, and decision making.**
  - This collaboration will lead to the common standards and protocols needed to promote development of new informatics tools.
- **EcoINFORMA should be involved in the highest levels of national information strategic planning and development, and be authorized to collaborate internationally.**
  - The broad swath of data types that this report finds must be integrated will naturally intersect with yet more kinds of information. It is important that informatics capabilities evolve toward universality; all information domains, including the ones of concern here, must be represented in deliberations concerning National Information Technology Research

187. PCAST. (2010). *Designing a digital future: Federally funded research and development in networking and information technology.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf

and Development (NITRD)[188] and the "interagency public access committee" that is to be established under the NSTC under the authority of the America COMPETES Reauthorization Act of 2010, Title I, Section 103.

– The standards and protocols for data and metadata, and information exchange, required for national initiatives must be developed on a global basis so that the United States can contribute to and benefit from international efforts such as GBIF and GEO BON; thus, a focal point for international cooperation is essential.

188. PCAST. (2010). *Designing a digital future: Federally funded research and development in networking and information technology.* Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf

Appendix A: List of Federal Ecological Monitoring Programs

The table that follows is an inventory of ground-based ecological monitoring programs carried out by Federal agencies (often in collaboration with other entities). These programs could provide a significant portion of the data needed for the QuEST Assessment proposed in this Report, but there are missing elements and some programs need strengthening, especially with regard to standards for data interoperability and regularity of data collection. See Appendix H for an explanation of abbreviations.

This list should not be considered definitive, nor complete, because (1) it is very difficult to gather these data from across the government with accuracy, (2) agencies included in the list self-reported and there are known Federal programs that declined to report, and (3) the budget figures indicated are only estimates because funding for multi-partner programs comes from multiple sources and these numbers were reported only by the lead agency.

Name of Program	Acronym	Website	Agency(-ies), and partners	Year funding initiated	Budget (in millions) 1995	2010	Data availability (2010)	FGDC metadata standard met?
Arctic Observing Network	AON	http://www.aoncadis.org/projects/	NSF	2007	—	9.25	http://www.aoncadis.org	Not stated[189]
Breeding Bird Survey	BBS	http://www.pwrc.usgs.gov/BBS/index.html	USGS, 3000 volunteers	1966	0.15	1.03	http://www.pwrc.usgs.gov/bbs	Yes
Clean Air Status and Trends Network	CASTNET	http://www.epa.gov/castnet	EPA, states, universities, Canada	1990	5.5	3.9	http://www.epa.gov/castnet	Not stated
Coastal Change Analysis Program	C-CAP	http://www.csc.noaa.gov/digitalcoast/data/ccapregional/index.html	NOAA, numerous federal, state and local cooperators (program run through cost-sharing)	1990	0.8	0.58	http://www.csc.noaa.gov/digitalcoast/data/index.html	Yes
Deep Sea Coral Research and Technology Program		http://coralreef.noaa.gov/deepseacorals	CCMA, NCCOS, NOAA, NOS	2009	—	2.5	http://coralreef.noaa.gov/resources/publicationsdata or http://www.nmfs.noaa.gov/habitat/2010_deepcoralreport.pdf	No
Environmental Monitoring and Assessment Program	EMAP	http://www.epa.gov/emap/index.html	EPA, federal agencies, universities, Canada, USSR	1988	40[190]	—	http://www.epa.gov/storet/ OR http://oaspub.epa.gov/emap/webdev_emap.search	Yes
Essential Fish Habitat Data Inventory	EFH	http://www.habitat.noaa.gov/protection/efh/habitatmapper.html	NOAA, NMFS, HC, HP	1996	—	4.9	www.habitat.noaa.gov/efhmapper	No
Forest Health Monitoring Program	FHM	http://fhm.fs.fed.us	BLM, EPA, NRCS, USFS, state forestry	1990	7.5	5.6	http://www.fs.fed.us/foresthealth/technology/adsm.shtml	Not stated
Forest Inventory and Analysis	FIA	http://www.fia.fs.fed.us	USFS	1930	15.5	75.4	http://www.treesearch.fs.fed.us/pubs/17334	Not stated
Global Lake Ecological Observatory Network	GLEON	http://www.gleon.org	NSF	2005	—	0.4	http://www.gleonrcn.org/index.php?pr=Data	Not stated
Long Term Ecological Research Network	LTER	http://www.lternet.edu	NSF, USFS, USDA-ARS, TNC	1980	10.4	29	http://www.lternet.edu/publications	Not stated

189. Throughout, "not stated" refers to information concerning the data on the website
190. The EMAP program was discontinued in 2006, although the data remain accessible.

Name of Program	Acronym	Website	Agency(-ies), and partners	Year funding initiated	Budget (in millions) 1995	Budget (in millions) 2010	Data availability (2010)	FGDC metadata standard met?
Multi-Resolution Land Characteristics Consortium	MRLC	http://www.mrlc.gov/index.php	BLM, C-CAP, EPA, EROS, GAP, LANDFIRE, NASA, NAWQA, NOAA, NPS, NRCS, OSM, USFS, USFWS, USGS	1992	10	2.9	http://pubs.usgs.gov/of/2008/1379	Yes
National Ecological Observatory Network	NEON	http://www.neoninc.org	LTER, USGS, universities, NEON Inc. (an independent 501(c)(3), funded by NSF), many others,	2009	—	86.74	not yet applicable	not yet applicable
National Fisheries Data Infrastructure	NFDI	http://www.nbii.gov/far/nfdi/index.aspx	USGS	2010	—	0.002	http://www.nbii.gov/far/nfdi/index.aspx	Not stated
National Hydrologic Benchmark Network	HBN	http://ny.cf.er.usgs.gov/hbn	NPS, USFS, USGS	1964	1.1	0.7	http://ny.cf.er.usgs.gov/hbn/flowchem.cfm	Not stated
National Land Cover Trends		http://landcovertrends.usgs.gov	EPA, NASA, USGS	2002	—	3	http://landcovertrends.usgs.gov/download/overview.html	No
National Marine Fisheries Service Stock Assessments		http://www.nmfs.noaa.gov/pr/sars/species.htm	NOAA-NMFS, 66 states and territories, universities, domestic and international fisheries commissions and organizations	1871	117	46.2	http://www.nmfs.noaa.gov/pr/sars/species.htm	No
National Park Service (Ecosystem) Inventory and Monitoring Program	I&M	http://science.nature.nps.gov/im/units/netn/index.cfm	NPS, EPA, FWS, NMFS, TNC, universities, volunteers	1991	2.225	45.5	http://science.nature.nps.gov/im/units/NETN/Reports/reports.cfm	Not stated
National Resources Inventory	NRI	http://www.nrcs.usda.gov/technical/NRI	USDA-NRCS, forestry agencies, conservation districts, natural resource groups, state governments	1977	8.5	22.9	http://www.nrcs.usda.gov/technical/NRI/2007/nri07erosion.html	Not stated
National Stream Quality Accounting Network	NASQAN	http://water.usgs.gov/nasqan	USGS, Mexico (for the Rio Grande)	1973	3	2.33	http://water.usgs.gov/nasqan/nasqan_publications.html	Not stated
National Streamflow Information Program[191]	NSIP	http://water.usgs.gov/nsip	USGS, state and local agencies, Federal Energy Regulatory Commission licensees	1888	80	27.7	http://pubs.usgs.gov/fs/2009/3020	Yes

191. Formerly the National Stream Gaging Program

Name of Program	Acronym	Website	Agency(-ies), and partners	Year funding initiated	Budget (in millions) 1995	Budget (in millions) 2010	Data availability (2010)	FGDC metadata standard met?
National Water Quality Assessment Program	NAWQA	http://water.usgs.gov/nawqa	USGS, EPA, NPS, Mexico, Canada, Advisory Council of federal agencies involved in water quality, local agencies	1991	8.5	66.5	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:0	Not stated
National Wetlands Inventory	NWI	http://www.fws.gov/wetlands	FWS, all federal resource agencies, states, local / regional governments, private sector	1978	7.75	5.3	http://www.fws.gov/wetlands/Data/index.html	Yes
NOAA Coastal Ocean Program	NOAA-COP	http://www.cop.noaa.gov	NOAA, DOI, state agencies, private industry, universities	1990	12.2	16	http://www.cop.noaa.gov/pubs/das/default.aspx	Not stated
NOAA National Estuarine Research Preserves	NERRS	http://www.nerrs.noaa.gov	NOAA, Mexico, EPA, DOI, DOE, DOD, NSF, state and local agencies, private landowners	1972	5.5	23	http://www.nerrs.noaa.gov/RCDefault.aspx?ID=56	Not stated
NOAA National Status and Trends Mussel Watch Program	NS&T	http://ccma.nos.noaa.gov/about/coast/nsandt/welcome.html	NOAA, EPA, states, municipalities, United Nations	1984	1.5	0	http://ccma.nos.noaa.gov/publications/MWTwoDecades.pdf http://ccma.nos.noaa.gov/about/coast/nsandt/download.html	Yes
Ocean Observatories Initiative	OOI	http://www.oceanleadership.org/programs-and-partnerships/ocean-observing/ooi/	NSF	2009	—	140	beginning 2013	Not stated
Phytoplankton Monitoring Network	PMN	http://www.chbr.noaa.gov/pmn	DOC, NCCOS, NOAA, NOS,	2001	—	0.48	http://www.ncddc.noaa.gov/website/PMN/viewer.htm	yes
Snowpack Telemetry	SNOTEL	http://www.wcc.nrcs.usda.gov/snow	NRCS, NWS, BOR, Canada, Mexico, Tribes, states, municipalities	mid 1930s	3.5	10.96	http://www.wcc.nrcs.usda.gov	Yes
The Marine Protected Areas Inventory	MPA	http://www.mpa.gov/dataanalysis/mpainventory	NOAA	2001	—	0.2	http://www.mpa.gov/dataanalysis	Yes
Toxics Release Inventory	TRI	http://www.epa.gov/tri	EPA	1986	Not reported	14.88	http://www.epa.gov/tri/tridata/index.htm	Not stated
U.S. National Phenology Network	USA-NPN	http://www.usanpn.org	NPS, USGS, tribes, universities, NGOs, and specialized networks	2007	—	1.1	http://www.usanpn.org/resources/biblio	No

Name of Program	Acronym	Website	Agency(-ies), and partners	Year funding initiated	Budget (in millions) 1995	2010	Data availability (2010)	FGDC metadata standard met?
USGS Water, Energy and Biogeochemical Budgets	USGS-WEBB	http://water.usgs.gov/webb	NPS, USACE, USFS, USGS, CRREL, universities, Puerto Rico	1991	1.5	2.2	http://water.usgs.gov/webb/publications.html	Not stated
Water Quality Exchange	WQX	http://www.epa.gov/storet/wqx/index.html	EPA	2007	—	0.425	http://www.epa.gov/storet/dbtop.html	Not stated
				Total	**342.13**	**651.58**		
				Adjusted to constant (2005) dollars	**438.44**	**583.58**		

Appendix B: List of Ecosystem Assessments

The table that follows is an inventory of ecological or ecosystem assessment programs carried out by Federal agencies and their partners, or by non-governmental entities funded by the government, organized by first year undertaken. Assessments draw on data collected by Federal agency / partner monitoring programs (see Appendix A). With certain exceptions, these assessments analyze the status and trends of the ecosystem of concern but not the value of the services afforded by that ecosystem. All of these could be part of the QuEST Assessment called for in this Report, but none is the comprehensive, nationwide report on all ecosystems the Working Group believes is required, nor are all of them taken together. Acronyms are expanded in Appendix H.

Name of Assessment	Date(s)	Description	Partners	Website
National Shellfish Register of Classified Estuarine Waters	1966 et seq. (5-year intervals)	Primarily focused on the status of shellfishing waters with respect to human health; data also collected on water quality and shellfish productivity, pollution sources and effects, and state shellfish management programs.	NOAA, NASA, FDA	http://gcmd.nasa.gov/records/GCMD_NOS00039.html
National Coastal Assessment (NCA)	1972, 1986, 1990, 1995, 2000	Assessment of estuarine and coastal data collected from thousands of stations along the coasts of the continental United States.	EPA's National Aquatic Resource Surveys	http://water.epa.gov/type/oceb/assessmonitor/nccr/index.cfm
Coastal Change Analysis Program	1972, 1986, 1990, 1995, 2000	Provided inventories of coastal intertidal areas, wetlands, and adjacent uplands by updating land cover maps.	NOAA Coastal Services Center	http://www.csc.noaa.gov/digitalcoast/data/ccapregional/index.html
Assessment of Ozone Depletion; Scientific Assessment of Ozone Depletion	1985, 1988, 1991, 1994, 1998, 2002, 2006, 2010	Provides data to inform policies of the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer.	NASA, NOAA, WMO, UNEP, other federal and international organizations	http://www.esrl.noaa.gov/csd/assessments/ozone/
Rangeland Inventory, Monitoring, and Evaluation Report	1989-2008	Ecological assessment, covering millions of acres across the West to better manage public lands, in part for renewable energy development.	BLM	http://www.blm.gov/wo/st/en/prog/more/rangeland_management/rangeland_inventory.html
Intergovernmental Panel on Climate Change (IPCC)	1990, 1995, 2001, 2007	Reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change.	UNEP, WMO (with strong U. S. participation)	http://www.ipcc.ch
National Acid Precipitation Assessment Program (NAPAP)	1990, 1996, 2005	Conducts acid rain research and monitoring and periodically assesses the costs, benefits, and effectiveness of Title IV of the 1990 Clean Air Act Amendments.	DOE, DOI, EPA, NASA, NOAA and USDA	http://ny.cf.er.usgs.gov/napap/index.cfm
National Assessment of Water Quality	1991 et seq.	Provides an understanding of water-quality conditions; of whether conditions are getting better or worse over time; and of how natural features and human activities affect those conditions.	USGS NAWQA program	http://water.usgs.gov/nawqa
NAWQA Ecological National Synthesis	1991 et seq.	Analysis of data collected by the NAWQA monitoring program on chemistry, hydrology, land use, stream habitat, and aquatic life in nearly 50 States.	USGS NAWQA program	http://water.usgs.gov/nawqa/ecology
NAWQA Study of Effects of Urbanization on Stream Ecosystems	1991 et seq.	Analysis of data collected by the NAWQA monitoring program on 9 urban areas around the country.	USGS NAWQA program	http://water.usgs.gov/nawqa/urban
Gap Analysis Program (GAP)	1992 et seq.	Identifies species and ecological communities that are not adequately represented in existing conservation lands to assure their sustainability.	USGS, DOD, EPA; states; private; academic; NGO	http://gapanalysis.usgs.gov
National Water Quality Inventory	1992, 1994, 1996, 1998, 2000, 2002, 2004	Characterizes water quality, identifies widespread water quality problems of national significance, and describes various programs implemented to restore and protect our waters.	EPA	http://water.epa.gov/lawsregs/guidance/cwa/305b/index.cfm

Name of Assessment	Date(s)	Description	Partners	Website
Agricultural Resources and Environmental Indicators (AREI)	1994, 1996-1997, 2003, 2006	Describes trends in resources used in and affected by agricultural production, as well as the economic conditions and policies that influence agricultural resource use and its environmental impacts	USDA, ERS	http://www.ers.usda.gov/publications/arei
USGS Biological and Environmental Status and Trends (BEST) Program	1994 et seq.	Assessment of changes in animal and plant habitats; analysis of impacts of land-use change, agricultural practices, etc.	USGS	http://biology.usgs.gov/status_trends
Status and Trends of the Nation's Biological Resources	1995, 1998	Described the major processes and factors affecting biological resources, and provided a snapshot of regional status and trends.	USGS	http://www.nwrc.usgs.gov/sandt
Soil and Water Resources Conservation Act (1977) Appraisal	1995-1996	Appraised the status and trends of soil, water, and related resources on non-Federal land and assessed capability to meet present and future demands; evaluated programs, policies, and authorities; developed a program to direct USDA soil and water conservation activities.	USDA, NRCS	http://www.nrcs.usda.gov/technical/rca
Mid-Atlantic Integrated Assessment (MAIA)[192]	1997 - 1998	Incorporated numerous state, regional, and national environmental monitoring programs into an assessment process specifically targeted to the management needs of EPA's Region III.	EPA, NOAA, USFS, USGS, GAP; Chesapeake Bay, Delaware Estuary, and Virginia Coastal Bays Programs	http://www.epa.gov/emap/maia
National Assessment of Coastal Vulnerability to Sea-Level Rise	1999 - 2001	Quantification of relative risk that physical changes will occur as sea-level rises based on: tidal range, wave height, coastal slope, shoreline change, geomorphology, and historical rate of relative sea-level rise.	USGS, Woods Hole Field Center	http://woodshole.er.usgs.gov/project-pages/cvi/
Regional Assessment of Land Use Effects on Ecosystem Structure and Function in the Central Grasslands	1999	Integrated assessment of the impacts of land use management on the central grassland region including the effects of heterogeneity in land use and soil type	EPA	http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/237
Gulf of Mexico Hypoxia Assessment	2000	Assessment of causes and consequences of Gulf hypoxia to provide scientific information to evaluate management strategies and identify gaps in understanding of this problem.	CENR task group, led by NOAA	http://oceanservice.noaa.gov/products/pubs_hypox.html
Forest Health Monitoring assessment	2001-2004, 2005, 2009	Annual analysis of status, changes, and trends in forest condition based data from ground plots and surveys, aerial surveys, and other biotic and abiotic data sources, to address forest health issues that affect the sustainability of forest ecosystems.	USDA, USFS, State Foresters, and other state and federal agencies and academic groups.	http://fhm.fs.fed.us

192. See also the Gulf of Mexico regional assessment described in Box III-3.

Name of Assessment	Date(s)	Description	Partners	Website
State of the Nation's Ecosystems	2002, 2008	Developed widely accepted indicators of ecosystem condition, and reported status and trends of those indicators. Committees comprise representatives from academia, government, industry, and non-profit environmental organizations; process open and transparent to all.	H. John Heinz Center for Science, Economics, and the Environment	http://www.heinzctr.org/ecosystems
Water Quality Assessment and Total Maximum Daily Loads Information (ATTAINS)	2002, 2004, 2006, 2008, 2010	Assessment of water quality conditions as reported by the states to EPA under Sections 305(b) and 303(d) of the Clean Water Act	EPA	http://www.epa.gov/waters/ir
National Assessment of Shoreline Change	2004 - 2007	Comprehensive analysis of shoreline movement that is regionally consistent, to provide information regarding past and present shoreline changes.	USGS	http://coastal.er.usgs.gov/shoreline-change
Landscape Fire and Resource Management Planning Tools Project (LANDFIRE)	2004 - 2009	Data on layers of vegetation composition and structure, surface and canopy fuel characteristics, and historical fire regimes.	USGS, USFS	http://www.landfire.gov/index.php
Fishery Independent Survey System (FINSS)	2004 - present	Conducts comprehensive fisheries-independent surveys in all of the eight large marine ecosystems within the U.S. EEZ.	NMFS, NOAA	http://www.st.nmfs.noaa.gov/st4/ifso/index.html
National Lakes Assessment (NLA)	2006 - 2010	Statistical survey of the condition of U.S. lakes to determine baseline data on ecological integrity for better management.	EPA's National Aquatic Resource Surveys	http://water.epa.gov/type/lakes/lakessurvey_index.cfm
National Rivers and Streams Assessment (NRSA), including the Wadeable Streams Assessment	2006; 2007 - 2011	Statistical survey of the condition of U.S. rivers and streams to determine baseline data on ecological integrity for better management.	EPA's National Aquatic Resource Surveys	http://water.epa.gov/type/rsl/monitoring/riverssurvey/riverssurvey_index.cfm and http://water.epa.gov/type/rsl/monitoring/streamsurvey/index.cfm
(Electronic) Report on the Environment	2008	Presents the best available indicators of national conditions and trends in air, water, land, human health, and ecological systems.	EPA	http://www.epa.gov/roe
National Wetland Condition Assessment (NWCA)	2009 - 2013	Statistical survey of the condition of U.S. wetlands to determine baseline data on ecological integrity for better management.	EPA's National Aquatic Resource Surveys	http://water.epa.gov/type/wetlands/assessment/survey/index.cfm
National Assessment of Coastal Change Hazards	2010	Identifies and quantifies the vulnerability of U.S. shorelines to coastal change hazards such as the effects of severe storms, sea-level rise, and shoreline erosion and retreat.	USGS Coastal and Marine Geology Program	http://coastal.er.usgs.gov/national-assessment

Appendix C: Ecosystem Services Valuation Projects

Examples of existing projects by Federal agencies to examine and explore the potential of ecosystem services valuation and market creation to improve management of ecosystems, mitigate adverse affects of human activities, and work toward sustainable ecosystems for the United States. The projects listed here were drawn from a compilation[193] made by the EPA Office of Research and Development's Ecosystem Services Research Program in conjunction with the National Ecosystem Services Partnership.[194] Abbreviations used here are explained in Appendix H.

Project Name	Agency	Bureau	Research Type	Project Goal(s)
Marine InVEST	DOC	NMFS	Valuation, social research	Identify where ecosystem services are provided and where they are consumed to reveal how resource management decisions will affect ecosystems, the economy, and human well being.
Comprehensive Valuation of Water-Related Recreational Activities along the Colorado River	DOI	NPS, USBR	Valuation, social research	Study economic values (including ecosystem service values) for water-related activities on Federal lands along the Colorado River, including white water rafting, camping, angling, and other recreational activities.
Conservation Banking/ Mitigation Banking	DOI	USFWS	Market design	Offset adverse impacts to endangered, threatened, and other at-risk species by offering incentives to conserve habitat, restore degraded habitat or preserve existing high value habitat and allowing "credits" earned to be sold to third parties in need of offsets for adverse impacts of their projects.
Amenity Value of Proximity to National Wildlife Refuges	DOI	USFWS	Valuation	Quantify the benefits to property owners associated with proximity to a National Wildlife Refuge to identify the amenity value of open space in wildlife refuges.
Valuing Ecosystem Goods and Services Provided by U.S. National Wildlife Refuges	DOI	USFWS	Valuation	Improve ability to assess economic benefits and costs associated with potential management responses to climate change impacts by estimating ecosystem services values for recreational fishing and hunting, wildlife observation, commercial fishing, carbon sequestration, waste assimilation, and protection from storms and sea level rise.
Migratory Species	DOI	USGS	Market design	Develop a formal methodology to account for the spatial dynamics of ecosystem services provided by migratory species to facilitate establishment of markets that promote cross-jurisdictional cooperative management and sustainable allocation of exploited migratory species.

193. Cox, L., & Almeter, A. (2011). *Draft Federal inventory on ecosystem services.* Retrieved from http://www.epa.gov/ecology/partnerships/federal_exchanges.htm

194. Duke University Nicholas Institute for Environmental Policy Solutions. *Documents and Presentations: Federal Exchanges on Ecosystem Services.* Retrieved from http://nicholasinstitute.duke.edu/ecosystem/nesp/documents-and-presentations

Project Name	Agency	Bureau	Research Type	Project Goal(s)
Ecosystem Portfolio Model (EPM)	DOI	USGS	Valuation, social research	Develop an internet tool to quantify accounting metrics for ecological values, quality of life indicators, and land prices in a model structured for stakeholder deliberations concerning the provision of ecosystem services. An example application is the Santa Cruz Watershed EPM, a water availability planning tool for the bi-national Santa Cruz watershed in Arizona/Sonora.
Social Values for Ecosystem Services (SolVES)	DOI	USGS	Valuation, social research	Develop a public-domain GIS tool for mapping social values on the landscape to facilitate public land planning and management decisions.
Assessment of Goods and Valuation of Ecosystem Services (AGAVES)	DOI, USDA	Inter-Agency Programs; ARS	Valuation	Determine usefulness of ecosystem service valuation for improving decision-making and determine the feasibility of valuation and decision support tools using the San Pedro watershed in southeastern Arizona as a pilot. To the extent feasible, the project will examine three broad approaches to environmental valuation: (a) procedures specifically designed for this project, which may include both stated preference and revealed preference methods for nonmarket valuation; (b) existing ecosystem services tools; and (c) economic benefit transfer techniques.
Chesapeake Bay Pilot	EPA	ESRP	Valuation, market design, social research	Explore cost-effectiveness and feasibility of policies to allow market] mechanisms to reduce the costs of meeting the Total Maximum Daily Loads (TMDLs) for nitrogen, phosphorus, and sediment required under Executive Order 13508, while at the same time promoting the creation or restoration of other ecosystem services.
Willamette Ecosystem Services Project (WESP)	EPA	ESRP	Valuation, market design, social research	Evaluate ecosystem services relevant to stakeholders; develop analytical tools that support land and water management decisions; explore impacts of alternative management strategies on the production of ecosystem service bundles.
Water Quality Trading	EPA	OW	Market design	Develop water quality trading programs that facilitate point to nonpoint source trading that can yield multiple environmental benefits beyond reductions of target pollutants.
Wetlands Compensatory Mitigation Program	EPA	OW	Market design	Compensate mitigation to restore, establish, enhance, or preserve wetlands, streams, or other aquatic resources to offset unavoidable adverse impacts.
Ohio River Basin Trading Project	EPA, USDA, EPRI		Market design	Trade credits across the region to allow power companies, farmers, and other industrial dischargers to work together to improve water quality, minimizing costs to the public and stakeholders.
Farmer Behavior and Climate Change	USDA	ERS	Market design, social research	Analyze farmer behavior and participation in trading programs.

Project Name	Agency	Bureau	Research Type	Project Goal(s)
Environmental Services from Wetlands	USDA	ERS	Valuation	Develop measures of cost of restoring and preserving wetlands and the values (when possible) and quantities of their ecosystems services.
Mission and Goals	USDA	OCE/ OEM	Valuation, market design	Develop uniform technical guidelines to measure benefits, protocols to report and verify benefits, and tools to create and expand markets for vital ecosystem services.
Northern California Coast community tree guide: benefits, costs, and strategic planning	USDA	USFS	Valuation, market design	Analyze costs and benefits of ecosystem services provided by urban trees.
Tolt River Watershed	USDA	USFS	Valuation, market design, policy research, social research	Value 23 ecosystem services provided by this 3,700-acre watershed as a case study.
National Grasslands Administration Program	USDA	USFS; ESA	Valuation	Determine value of grasslands ecosystem services (carbon storage, water quality, wildlife habitat, pollinators, aesthetics, cultural) to human well-being.
Carbon Capital Fund	USDA	USFS; NFF	Valuation, market design	Examine carbon storage, water quality, cultural, wildlife habitat and other ecosystem services, including some market research.

Appendix D: Data Availability

Survey of national environmental monitoring programs with regard to the availability of the data they generate on Data.gov or other government agency website. Data in this table were compiled in October 2010. Abbreviations are explained in Appendix H.

Name of Program	Acronym	Agency	Datasets in Data.gov ?	What happens at Data.gov when it is searched for this program's data?
Alaska Fisheries Information Network	AKFIN	NOAA	No	Some datasets available at NBII.gov
Arctic Observing Network	AON	NSF	No	
Breeding Bird Survey	BBS	NBS	Minimal	Accesses one dataset; Links to NationalAtlas.gov website
Clean Air Status and Trends Network	CASTNET	EPA	Yes	Also links to EPA, CASTNET website
Coastal Change Analysis Program	C-CAP	NOAA	No	Links to NOAA, Coastal Services Center website
Coastal Ocean Program	NOAA-COP	NOAA	No	Some datasets available at NBII.gov
Deep Sea Coral Research and Technology Program		NOAA	No	Some datasets available at NBII.gov
Environmental Monitoring and Assessment Program	EMAP	EPA	Partial	Access to EMAP; not to specific datasets; some link back to USGS website
Essential Fish Habitat Data Inventory	EFH	NOAA	No	Some datasets available at NBII.gov
Fisheries Information Network	FIN		No	Some datasets available at NBII.gov
Forest Health Monitoring Program	FHM	USFS; EPA	No	
Forest Inventory and Analysis	FIA	USFS	No	
Gap Analysis Program	GAP	USGS	No	Links to USGS, GAP website
Global Lake Ecological Observatory Network	GLEON	NSF	No	
Landsat	Landsat	USGS, NASA	Yes	Also links to website
Long Term Ecological Research Network	LTER	NSF	No	NBII.gov links to website
Long-term Ecological Monitoring R&D, Olympic Peninsula, Washington	—	USGS, DOI	No	Some datasets available at NBII.gov
Multi-Resolution Land Characteristics Consortium	MRLC	multi[5]	Yes	Datasets are accessed
National Air Monitoring Stations / State and Local Air Monitoring Stations	NAMS/ SLAMS	EPA-OAQPS	Yes	Also links to EPA website
National Atmospheric Deposition Program / National Trends Network	NADP/NTN	USGS	No	
National Ecological Observatory Network	NEON	NEON[6]	No	NBII.gov links to website

Name of Program	Acronym	Agency	Datasets in Data.gov ?	What happens at Data.gov when it is searched for this program's data?
National Environmental Satellite, Data, & Information Service	NESDIS	NOAA	Yes	Also links to website
National Estuarine Research Preserves	NERRS	NOAA	No	Some datasets available at NBII.gov
National Estuarine Research Reserves	—	NOAA	No	NBII links to website
National Fisheries Data Infrastructure	NFDI	USGS	No	NBII links to website
National Hydrologic Benchmark Network	HBN	USGS	Minimal	One dataset available; links to website; specific datasets found at NBII.gov
National Land Cover Trends		USGS	No	Some datasets available at NBII.gov
National Marine Fisheries Service Stock Assessments	NMFS Stock Asmnts	NMFS	No	Links to NOAA website
National Marine Sanctuary Program	—	NOAA	Yes	Also links to website
National Park Ecosystem Monitoring Program	—	NPS	No	Some datasets available at NBII.gov
National Park Service Inventory and Monitoring Program	NPS I&M	NPS	No	
National Pollutant Discharge Elimination System Permit Program	NPDES	EPA	Yes	Also links to datasets on the website
National Resources Inventory	NRI	NRCS	Yes	Also links to USGS website (not USDA)
National Status and Trends Benthic Surveillance Program	NS&T	NOAA	No	Available at geodata.gov
National Status and Trends Mussel Watch Program	NS&T	NOAA	No	Available at geodata.gov
National Stream Quality Accounting Network	NASQAN II	USGS	Yes	Also links to USGS website
National Streamflow Information Program	NISP	USGS	Yes	Also links to USGS website
National Water Quality Assessment Program	NAWQA	USGS	Yes	Also links to website
National Wetlands Inventory	NWI	FWS	No	Links to USGS, NWI website
Natural Resource Vital Signs Monitoring Network	—	NPS	No	Some datasets available at NBII.gov
Ocean Observatories Initiative	OOI	NSF	No	
Pacific Fisheries Information Network	PacFIN		No	Some datasets available at NBII.gov
Photochemical Assessment Monitoring Stations	PAMS	EPA	No	Available at Aerometric Information Retrieval System (in widget format) for (AIRS) data
Phytoplankton Monitoring Network	PMN	NOAA	No	Some datasets available at NBII.gov
Puget Sound Ambient Monitoring Program	PSAMP	WDFW	No	Some datasets available at NBII.gov
Remote Automated Weather Station	RAWS (or AWS)	multi[7]	No	Some datasets available at NBII.gov

Name of Program	Acronym	Agency	Datasets in Data.gov ?	What happens at Data.gov when it is searched for this program's data?
Snowpack Telemetry	SNOTEL	NRCS	No	Some datasets available at NBII.gov
The Marine Protected Areas Inventory	MPA	NOAA	No	Some datasets available at NBII.gov
Toxics Release Inventory	TRI	EPA	Partial	Some datasets; also available as Widget tool
U.S. National Phenology Network	USA-NPN	USGS	No	
USGS Acid Rain Watersheds	—	USGS	No	Some datasets available at NBII.gov
USGS Water, Energy and Biogeochemical Budgets	USGS-WEBB	USGS	No	Some datasets available at NBII.gov
Water Quality Exchange	WQX	EPA	No	Some datasets available at NBII.gov
Western Pacific Fisheries Information Network	WPacFIN	NOAA	No	Some datasets available at NBII.gov

Appendix E: Statement of Work

President's Council of Advisors on Science and Technology (PCAST)

Statement of Work

Biodiversity Preservation and Ecosystem Sustainability Study

Background

Natural ecosystems, composed of biodiversity, provide services that are essential to human well-being. Sustainable agricultural output, forestry products, and fisheries, among other benefits such as the filtration of air and water, all depend on well-functioning ecosystems. In short, nature provides many benefits to society, and poor functioning of those resources leads to immediate societal impacts.

The United States, like all countries in the world, is experiencing ever-increasing demands on ecosystem services, which in turn affect its ability to protect biodiversity for future generations. These demands occur both on a continuing daily basis and episodically from acute, crisis-level events. The nation needs the capability to make scientifically informed decisions for the long-term management of biodiversity and ecosystems to ensure their sustained capacity to provide essential services; it needs the capacity to secure these living resources in the face of natural or human-caused threats, and it needs the ability to make rapid, science based decisions in the face of crises.

Federal agencies have been collecting, for decades, data that are relevant to biodiversity and ecosystems. These existing raw data, if assembled, combined, and evaluated using innovative informatics technologies, visualization tools, and analytical science, are highly likely to produce knowledge that can contribute to addressing questions of ecosystem security and sustainability. Informatics-enabled assessments of what is known also can be used to guide ongoing and future research and monitoring efforts, environmental planning, and decision-making.

Problem Statement

Sustaining biodiversity and ecosystem services in the face of the interconnected and increasingly global suite of environmental problems—including habitat fragmentation, pollution, and climate change—requires a coordinated U.S. research effort that can inform adaptive means of planning, decision-making, management, and preservation at multiple scales (from local to landscape to global). The United States can capitalize on decades of research investment through innovations in information infrastructure that will enable targeted research that will in turn inform policy decisions and new institutional arrangements (e.g., for stakeholder engagement, international assessment, markets, etc.

Study Objective

PCAST will assemble a Working Group to conduct a study that will identify research priorities, the supporting informatics developments, and the related institutional arrangements necessary for protecting biodiversity and managing ecosystems to ensure their long-term sustainability and security in the face of critical challenges. Particular attention will be paid to how such a program can address concerns of adaptation to global change, given the societal urgency of this issue.

The BPES Working Group is mindful of the underpinnings of the U.S. capabilities in science and technology: the fundamental importance of basic research, the computing and network infrastructures that support it, and the institutional issues that affect U.S. scientists' ability to collaborate internationally. Its recommendations will be informed by data provided by invited experts from government, academia, and other sectors, including those who can speak to international concerns. The Working Group, keeping in mind terrestrial, aquatic, and marine ecosystems, will address the following (draft) topic areas and example questions:

1. Social precursors and feedbacks to ecosystem change to enable Federal Agencies better to predict anthropogenic environmental change that threatens biodiversity preservation, ecosystem services, and biosecurity. Differing human demands on the services that ecosystems provide often compete with one another, increasing the challenge to managing ecosystems for sustainability. Feedbacks between social dynamics and ecosystems complicate prediction and can create both stabilizing and destabilizing patterns

    – Are analytical, synthetic, and predictive methods adequate for the President to be able to address the consequences of human–ecosystem dynamics for biodiversity preservation, for ecosystem services, and for biosecurity?

    – What is the scope for using social precursors (changes in price expectations, social norms etc) in modeling anthropogenic environmental change? How can existing monitoring systems be augmented to include such precursors?

2. Economic valuation of ecosystem services to enable Federal Agencies and other bodies to manage trade-offs in the provision of ecosystem services, and to ensure that changes in the value of ecosystems are recorded in national income and wealth accounts, thus assisting in making choices that allow for appropriate management of existing ecosystems and to sustain their benefits.

    – Have the philosophical underpinnings adequately been worked out for placing biological and ecological data and information within the social and economic context?

- What are current best practices in estimating the value of non-marketed ecosystem services, and how can they be used to supplement biological and ecological data? What is needed to assure appropriate measurement of changes in the natural wealth of the USA?
- Do economic valuations of present and future ecosystem services provide accurate information so that management and preservation strategies can be developed to assure sustainability? How can this be encouraged?

3. Human and environmental health impacts, including emergent diseases, of actions in all of these areas.
   - Are there tools available to conduct rigorous studies of cause and effect and to support rigorous assessment of risk? Do new, innovative tools need to be developed?
4. Sampling protocols whereby the U.S. can ascertain the extent and status of biodiversity in the U.S.
   - What are the desirable scales at which to gather the several necessary kinds of data? Are these data being collected? What is the appropriate role of each sector of society in collecting, managing, and using these data?
   - What new and innovative tools need to be deployed to gather data more effectively?
5. Informatics and coordination infrastructures to enable the U.S. to benefit from data and information already gathered, more efficiently handle and integrate new data and information, and utilize these in a coordinated manner across the government to respond to crises and to better sustain the ecosystems that provide benefits to our Nation.
   - Are current data and information management infrastructures adequate to enable retrieval, combination, analysis and synthesis of data gathered by different sectors and at different scales? What new and innovative information infrastructures might need to be deployed?
   - What cross-sectoral, and cross-governmental, mechanisms and partnerships are needed to increase effectiveness of coordination of management and crisis-response?
6. National assessment(s) of the status and trends of U.S. ecosystems, including ecosystem change resulting from changes in climate, globalization, etc.
   - Is the breadth and depth of our knowledge of changes in the status and trends of biodiversity and ecosystem services in the U.S. and elsewhere adequate to understand and manage their causes and consequences?
   - Who/what sector should be responsible for what kind of data gathering?
     - » Are data and information being shared across sectors in an appropriate and effective way?
     - » Are federal government agencies gathering and sharing data effectively?
7. The international context of biodiversity and ecosystems, and the connections that the U.S. needs to contribute to, build, or maintain.
   - What is the appropriate role for the U.S. to play in international organizations concerned with the observation, monitoring and assessment of change in biodiversity and ecosystems

such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the Global Biodiversity Information Facility (GBIF), the Group on Earth Observations Biodiversity Observation Network (GEO BON), and the international scientific unions?

- What domestic infrastructures will enable the U.S. to be an effective leader in the international biodiversity and ecosystems arena?

8. Using biodiversity and ecosystem services assessments to identify where the greatest returns can be found from public investments in or incentives for environmental protection and restoration.

    - Are there tools that facilitate informed management of human life-sustaining agricultural and forest lands, fisheries and other resources through the application of research results?

Inputs to the Study

As part of the data gathering effort, the working group will have background reading materials and receive briefings on: 1) the workshop and report on Integrating Biodiversity and Ecosystems Information Systems: Transparency, Participation & Collaboration (2009); 2) A Research Framework to Improve Management for and Decision Making Associated with Ecosystem Services (2010); 3) the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2010); 4) the public-private effort on the "State of the Nation's Ecosystems" (1997-2008); 5) the National Ecological Observatory Network (funded to begin in FY2011); as well as 6) any other available or forthcoming reports on topics appropriate to the charge of this study; 7) initiatives and efforts being organized within and among relevant USG agencies; and 8) similar studies conducted in the United Kingdom and the European Union.

Appendix F: Expert Input into This Report

The PCAST Biodiversity Preservation and Ecosystem Sustainability Working Group is grateful for the input of the experts listed below. Listing here does not imply endorsement of this report or its recommendations. Acronyms are explained in Appendix H.

Nancy H. Sutley
Chair
CEQ

Gary S. Guzy
Deputy Director and General Counsel
CEQ

Michael J. Boots
Chief of Staff
CEQ

Jason E. Bordoff
Associate Director for Energy & Climate Change
CEQ

Nicole Buffa
Associate Director, Communities, Environmental Protection & Green Jobs
CEQ

Erika M. Feller
Deputy Associate Director, Ecosystems
CEQ

Geoffrey Heal
Professor
Columbia University

David Schindel
Executive Director
Consortium for the Barcode of Life

Ron D'Or
Professor
Dalhousie University

Kerri Ann Jones
Assistant Secretary for Oceans & International Environmental & Scientific Affairs
Department of State

Nathaniel Keohane
Chief Economist
Environmental Defense Fund

Paul Anastas
Assistant Administrator (R&D)
EPA

Philip Juengst
Acting Chief, Budget Formulation
EPA

Al McGartland
Director, NCEE
EPA

David Simpson
Director, Ecosystem Economic Studies, NCEE
EPA

Heather Klemick
Economist, NCEE
EPA

Dina Kruger
Director, Climate Change Division
EPA

Rona Birnbaum
Chief, Climate Science and Impacts Branch
EPA

Denice Shaw
Environmental Scientist
EPA

Llael Cox
Student Services Contractor
EPA

Barry Gold
Program Officer
Gordon & Betty Moore Foundation

Mark Gaden
Communications Director
Great Lakes Fishery Commission

Robert Stavins
Professor
Harvard University

Robert Waide
Executive Director
LTER Network

Woody Turner
Science Mission Directorate
NASA

David Schimel
Director
NEON

Jane Lubchenco
Administrator
NOAA

Charles Alexander
Assistant Administrator
NOAA

Holly Bamford
Deputy Assistant Administrator, NOS
NOAA

Steve Murawski
Science Advisor, NMFS
NOAA

Russell Brainard
Supervisory Oceanographer, NMFS/PIFSC
NOAA

John E Lowell
Captain, NOS/OCS
NOAA

Steven Fancy
Chief, Inventory and Monitoring Division
NPS

Penelope Firth
Deputy Division Director
NSF

Todd Crowl
Program Officer
NSF

Judy Skog
Program Officer
NSF

Nancy Huntly
Program Officer
NSF

Sylvia Spengler
Program Officer
NSF

Sally Ericsson
Associate Director for Resource Programs
OMB

John P. Holdren
Director
OSTP

Sherburne B. Abbott
Associate Director for Energy and Environment
OSTP

Christopher L. Greer
Assistant Director for Information Technology
R&D
OSTP

Katherine L. Jacobs
Assistant Director for Climate Adaptation and
Assessment
OSTP

Bruce D. Rodan
Senior Policy Analyst
OSTP

Rita E. Curtis
Senior Policy Analyst
OSTP

Jerry L. Miller
Senior Policy Analyst
OSTP

Sarah R. Carter
Policy Analyst
OSTP

Hal Mooney
Professor
Stanford University

Daphne Fautin
Professor
University of Kansas

Marilyn Larsen
Research Program Manager
University of Wisconsin

Catherine Wotecki
Undersecretary for Research, Education and Economics
USDA

Ann Bartuska
Deputy Undersecretary for Research, Education and Economics
USDA

William Hohenstein
Director, Climate Change Program Office
USDA

Michael Shannon
Office of the Chief Economist
USDA

Ann Lichens-Park
National Program Leader, NIFA
USDA

Jeffery Goebel
Acting Director, NRCS Resource Inventory Division USDA

Mark Nechodom
Acting Director, Office of Environmental Markets
USDA

Gladys Cotter
Associate Chief Biologist for Information
USGS

Douglas Beard
Chief, NCCWSC
USGS

Robin O'Malley
Science Advisor, NCCWSC
USGS

Gerald Guala
Director, Integrated Taxonomic Information System
USGS

Kate Kase
NBII National Program Officer
USGS

Peter Murdoch
Program Coordinator
USGS

Linn Kwan
Ecosystems Mission Area Coordinator
USGS

Appendix G: Acknowledgements

The PCAST and its Biodiversity Preservation and Ecosystem Sustainability Working Group wish to express gratitude to the following individuals, who contributed in various ways to the preparation of this report:

Alan Anderson
Writer
Science and Technology Policy Institute

Anthony J. "TJ" Augustine
Student Volunteer
Office of Science and Technology Policy

Michelle Costanzo
Student Volunteer
Office of Science and Technology Policy

Danielle Evers
AAAS Fellow
Office of Science and Technology Policy

Gera Jochum
Policy Analyst
Office of Science and Technology Policy

Brandon Ledford
Student Volunteer
Office of Science and Technology Policy

Andrew J. "AJ" Sedgewick
Researcher
Science and Technology Policy Institute

Deborah Shapley
Writer
Science and Technology Policy Institute

Deborah Stine
Executive Director, PCAST
Office of Science and Technology Policy

Appendix H: Abbreviations Used in This Report

ACES	A Community on Ecosystem Services
AGAVES	Assessment of Goods and Valuation of Ecosystem Services
AKFIN	Alaska Fisheries Information Network
AON	Arctic Observing Network
API	Application Program Interface
AREI	Agricultural Resources and Environmental Indicators
ARIES	Artificial Intelligence for Ecosystem Services
ATTAINS	Assessment, TMDL Tracking and ImplementatioN System
AWS	Automated Weather Station
BBS	Breeding Bird Survey
BEST	USGS Biological and Environmental Status and Trends Program
BLM	Bureau of Land Management
CASTNET	Clean Air Status and Trends Network
CBD	Convention on Biological Diversity
C-CAP	Coastal Change Analysis Program
CCMA	Center for Costal Monitoring and Assessment
CEAP	Conservation Effects Assessment Program
CENRS	Committee on Environment, Natural Resources, and Sustainability (previously CENR)
CEQ	Council on Environmental Quality
CISET	Committee on International Science, Engineering and Technology
CONABIO	National Commission for Knowledge and Use of Biodiversity (Mexico)
CROI	Conservation Return on Investment
CRP	Conservation Reserve Program
CRREL	Cold Regions Research and Engineering Laboratory
CVI	Coastal Vulnerability Index
DIVERSITAS	An international program of biodiversity science
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
EBI	Environmental Benefits Index
EcoINFORMA	Ecoinformatics-based Open Resources and Machine Accessibility
EDGAR	Electronic Data Gathering, Analysis, and Retrieval System
EEZ	Exclusive Economic Zone
EFCA	Ecosystem Function Conservation Areas

EFH	Essential Fish Habitat Data Inventory
EIS	Environmental Impact Statement
EPRI	Electric Power Research Institute
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
EPM	Ecosystem Portfolio Model
EQIP	Environmental Quality Incentives Program
EROS	Earth Resources Observation Systems
ERR	Economic Research Report
ERS	Economic Research Service
ESA	Ecological Society of America
ESI	Environmental Sensitivity Index
ESRP	Ecosystem Services Research Program (EPA)
ESSP	Earth Systems Science Partnership
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FHM	Forest Health Monitoring Program
FIA	Forest Inventory and Analysis
FIN	Fisheries Information Network
FINSS	Fishery Independent Survey System
FIPS	Federal Information Processing Standards
GAO	General Accounting Office
GAP	Gap Analysis Program
GBIF	Global Biodiversity Information Facility
GDP	Gross Domestic Product
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations - Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse Gas
GLEON	Global Lake Ecological Observatory Network
GOOS	Global Ocean Observing System
GSMFC	Gulf Stats Marine Fisheries Commission
GYE	Greater Yellowstone Ecosystem
HBN	National Hydrologic Benchmark Network
HC	Habitat Conservation
HIA	Health Impact Assessment
HP	Habitat Protection
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development

ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Program
IHDP	International Human Dimension Program on Global Environmental Change
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Serves
IPCC	Intergovernmental Panel on Climate Change
ITIS	Integrated Taxonomic Information System
IWIBEIS	Interagency Workshop on Integrating Biodiversity and Ecosystems Information Systems
LANDFIRE	Landscape Fire and Resource Management Planning Tools Project
LTER	Long Term Ecological Research Network
MEA	Millennium Ecosystem Assessment
MAIA	Mid-Atlantic Integrated Assessment
MPA	The Marine Protected Areas Inventory
MRLC	Multi-Resolution Land Characteristics Consortium
N	Nitrogen
NADP/NTN	National Atmospheric Deposition Program / National Trends Network
NAMS/SLAMS	National Air Monitoring Stations/State and Local Air Monitoring Stations
NAPAP	National Acid Precipitation Assessment Program
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
NASQAN	National Stream Quality Accounting Network
NAWQA	National Water Quality Assessment Program
NBII	National Biological Information Infrastructure
NCA	National Coastal Assessment
NCBI	National Center for Biological Informatics
NCCOS	National Centers for Coastal Ocean Science
NCEE	National Center for Environmental Economics
NEON	National Ecological Observatory Network
NEPA	National Environmental Protection Act
NERRS	NOAA National Estuarine Research Preserves
NESDIS	National Environmental Satellite, Data, and Information Service
NESP	National Ecosystem Services Partnership
NFCP	National Forest Conservation Program
NFDI	National Fisheries Data Infrastructure

NFF	National Forest Foundation
NGO	Non-Governmental Organization
NHD	National Hydrography Dataset
NIEHS	National Institute of Environmental Health Sciences
NIGMS	National Institute of General Medical Sciences
NIH	National Institutes of Health
NIPA	National Income and Product Accounts
NISC	National Invasive Species Council
NISP	National Streamflow Information Program (formerly National Stream Gaging)
NIST	National Institute of Standards and Technology
NITRD	National Information Technology Research and Development
NLCD	National Land Cover Dataset
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOAA-COP	NOAA Coastal Ocean Program
NOS	National Ocean Service
NPDES	National Pollutant Discharge Elimination System permit program
NPS	National Park Service
NPS I & M	National Park Ecosystem Inventory and Monitoring Program
NRCS	Natural Resources Conservation Service
NRI	National Resources Inventory
NS&T	NOAA National Status and Trends
NSF	National Science Foundation
NSTC	National Science and Technology Council
NWI	National Wetlands Inventory
OECD	Organization for Economic Cooperation and Development
OEM	Office of Environmental Markets
OGWG	Open Government Working Group
OMB	Office of Management and Budget
OOI	Ocean Observatories Initiative
ORD	Office of Research and Development
OSEC	Office of the Secretary
OSM	Office of Surface Mining
OSTP	Office of Science and Technology Policy
OW	Office of Water (EPA)
PacFIN	Pacific Fisheries Information Network
PAD-US	Protected Areas Database of the United States
PAMS	Photochemical Assessment Monitoring Stations

PCAST	President's Council of Advisors on Science and Technology
PE	Program Effectiveness
PES	Payments for Ecosystem Services
PII	Personally Identifiable Information
PMN	Phytoplankton Monitoring Network
PSAMP	Puget Sound Ambient Monitoring Program
PIFSC	Pacific Islands Fisheries Science Center
QuEST	Quadrennial Ecosystem Status and Trends Assessment
RAWS	Remote Automated Weather Station
RCA	Resource Conservation Act
REDD	Reducing Emissions from Deforestation in Developing Countries
REMAP	Regional Environmental Monitoring and Assessment Program
RISA	Regional Integrated Sciences and Assessment
ROI	Return on Investment
SEC	Securities and Exchange Commission
SEEA	System of integrated Environmental and Economic Accounting
SIS	Species Information System
SLCP	Sloping Land Conservation Program
SNIB	National Information System on Biodiversity
SNOTEL	Snowpack Telemetry
SolVES	Social Values for Ecosystem Services
TEEB	The Economics of Ecosystems and Biodiversity
TMDL	Total Maximum Daily Loads
TRI	Toxics Release Inventory
TWG	Targeted Watershed Grant
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNGA	United Nations General Assembly
UNSNA	United Nations System of National Accounts
USACE	U. S. Army Corps of Engineers
USAID	U. S. Agency for International Development
USA-NPN	U. S. National Phenology Network
USBR	U. S. Bureau of Reclamation
USDA	U. S. Department of Agriculture
USFS	U. S. Forest Service
USFWS	U. S. Fish and Wildlife Service
USGS	U. S. Geological Survey
UUID	Universally Unique Identifier

WATERS	Watershed Assessment, Tracking & Environmental ResultS
WCRP	World Climate Research Program
WEBB	USGS Water, Energy and Biogeochemical Budgets Program
WESP	Willamette Ecosystem Services Program
WMO	World Meteorological Organization
WPacFIN	Western Pacific Fisheries Information Network
WQX	Water Quality Exchange
WRB	Willamette River Basin
WRI	World Resources Institute