ECOLOGICAL FORECASTING




AGENDA FOR THE FUTURE

Committee on Environment and Natural Resources
Subcommittee on Ecological Systems

Ecological Forecasting: Agenda for the Future

It Begins with a Need

Forecasting the effects of environmental change on agricultural ecosystems supports this vitally important industry and ensures the health and well-being of U.S. citizens and those of many nations around the world.

The stakes in preserving our ecosystems – and the fragile webs that bind them – are enormous. Whether we realize it or not, the health of the U.S. economy is inextricably linked to the health of our nation's ecosystems, and the goods and services those ecosystems deliver to our economy.

Consider a small sampling of the goods. Agricultural ecosystems provide over $200 billion annually. Marine ecosystems provide annually $27 billion in fisheries alone. And ecosystems do more than furnish food and fiber. Their "services" include providing clean air and water, detoxifying and decomposing wastes, pollinating crops and natural vegetation, and providing drought and flood control and recreational opportunities. To sustain the delivery of these goods and services, we need to anticipate how ecosystems will respond to natural and human stresses.

Ecological forecasts predict the effects of biological, chemical, physical, and human-induced changes on ecosystems and their components.

Today, at the beginning of the 21st century, the science community is poised to capitalize on research opportunities and thereby enhance the way we anticipate and manage ecosystem change. Recent technological innovations in computer science and quantitative analysis, nanotechnology, information and sensing technologies, genomics, systematic biology, and ecological theory make it possible to consider ecological forecasts that were not feasible only a few years ago.

What is Ecological Forecasting?

Ecological forecasts predict the effects of biological, chemical, physical, and human-induced changes on ecosystems and their

Forecasting the effects of stress on natural ecosystems helps sustain the aesthetic and economic vitality of U.S. recreation and tourism industries.

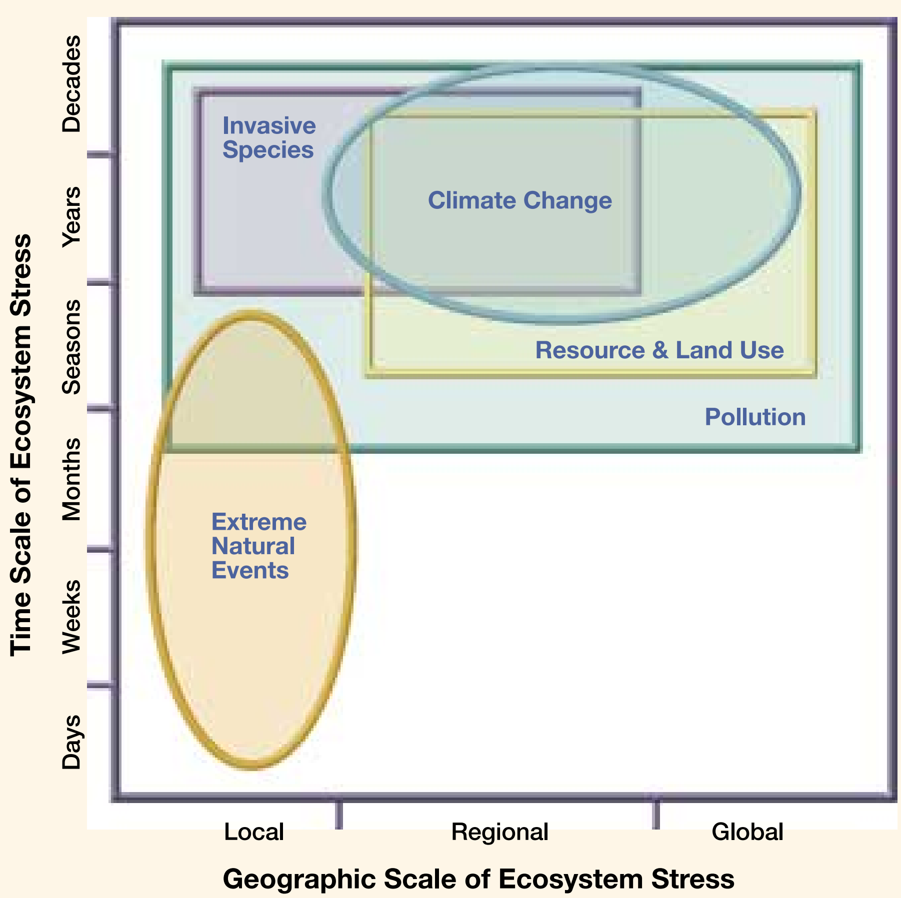
components. These forecasts do *not* guarantee what is to come; instead, they offer scientifically sound estimations of what is likely to occur.

Such forecasts answer "What will happen if …" questions tied to these changes. Short-term forecasts, such as predicting land-fall of toxic algal blooms, are similar to those done for weather and hurricane prediction. However, many of these short-term events have both immediate and long-term ecological impacts. For example, a catastrophic insect infestation or wildfire could allow major ecosystem shifts more readily than would otherwise occur. Similarly, major flood-induced nutrient influx to freshwater or coastal systems could impose longer-term changes in productivity or shifts to new ecosystem states.

Forecasting large-scale, long-term ecosystem changes is more akin to macroeconomic forecasts that build from expert judgment, analysis, and assessment, in addition to numerical simulation and prediction. Forecasts of such broad-based, long-term effects are particularly important because some of the most severe and long-lasting effects on ecosystems may result from chronic influences that are subtle over short time frames.

To sustain our valuable ecosystem goods and services, we have to understand how ecosystems function and interact and, most importantly, forecast how they will be affected by change.

Forecasting the impacts of catastrophic events, like wildfire, drought, and flood, helps protect ecosystems, especially those at risk, so we can ensure long-term delivery of goods and services, decrease short-term negative impacts, and minimize harm to people and the economy.



These five key causes of ecological change play out and interact *on a wide range of time and space scales. Even this oversimplified graph suggests that one of the greatest forecast challenges will be to predict the cumulative impacts of multiple stresses.*

What are the Benefits of Ecological Forecasts?

Ecological forecasts help resource managers (such as superintendents of national parks) better understand their options and the likely effects of their decisions. They help managers anticipate the consequences of their actions.

Ecological forecasts help focus information exchange at the science/policy interface. Focusing discussions around the need for and confidence in forecasts, helps identify the data, information, and predictions with the most significant economic, environmental, and policy implications.

Developing and testing ecological forecasts highlight uncertainties and weaknesses, and thereby help science managers set research, monitoring, modeling, and assessment priorities.

The Need for Ecological Forecasts

The five causes of ecosystem change provide a framework for ecological forecasting needs.

Extreme Natural Events – Such events include fire, floods, droughts, hurricanes, windstorms, and some toxic algal blooms. While extreme natural events are largely outside the control of natural resource managers, the ability to predict their occurrence and ecosystem effects, as well as their interactions with other causes of change, are important for planning management and response activities to minimize damage and enhance ecosystem resilience.

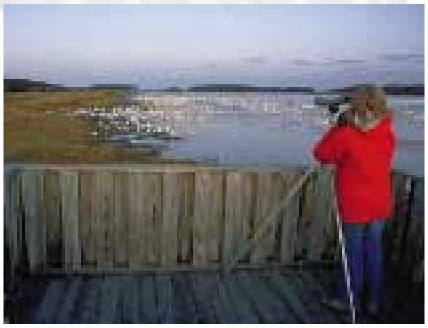
Climate Change – As certainty about the likelihood and magnitude of climate changes increases, the need for resource managers and policy makers to plan to minimize impacts on species, ecosystems, and ecological goods and services becomes more urgent. Current needs include forecasts of the interaction of climate change and variability with other stresses on ecological goods and services, particularly the distribution of species and the availability of clean water.

Land and Resource Use – Ecosystem changes take place in the context of ongoing changes in land and resource use. Forecasts of the far-reaching implications of these shifts on ecosystems, and their impacts on society, are needed. Current needs include forecasts of changes in the health and productivity of the natural and managed ecosystems that are critical in providing food and fiber to the U.S. economy — especially agricultural, forest, and rangeland ecosystems.

Pollution – Concerns about the presence of potentially harmful chemicals and excess nutrients in the environment remain a top concern. Current needs include forecasts of the effects of air pollution and land-based activities (for example, agricultural production, forest harvest) on terrestrial, freshwater, and marine ecosystems.

Land and resource managers make crucial decisions that affect the well-being of ecosystems for decades to come. Good forecasts of the consequences of those decisions will lead to better-informed decisions.

Invasive Species – Invasive species are species that are introduced intentionally or unintentionally from other areas, and are capable of spreading rapidly and replacing native species. These invaders exist in nearly all U.S. ecosystems and pose potential threats to the integrity of our nation's landscapes, biodiversity, and ecosystems *and* annually cost billions of dollars to control. Current needs include forecasts of the introduction, spread, and ecological effects of potential and already-introduced species.

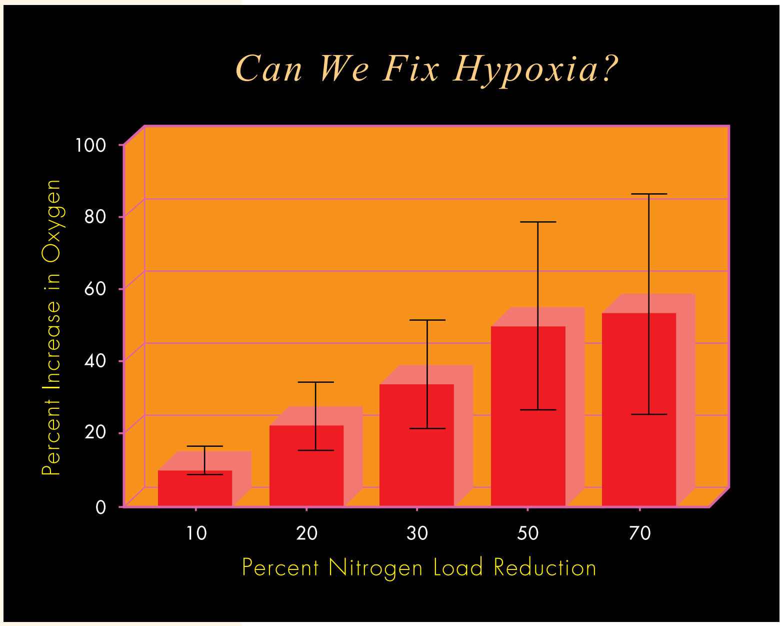


Forecasts of ecosystem impacts of natural variability and human interactions will help sustain enjoyment of our healthy natural ecosystems.

Interactive Effects – Most ecosystems throughout the United States are subject to multiple causes of ecological change. For example, an extreme natural event (perhaps fire) may open the door for new species invasions, and the success of that invader may be enhanced by altered climate (new precipitation and temperature patterns), the extent to which the land and related resources are used, and the chemical condition of the environment being invaded (pollution). Building the ability to forecast the cumulative effects of these multiple stresses is one of ecology's most significant challenges.

Examples of Ecological Forecasts

Hypoxia – a massive 15,000 km^2 area of depleted oxygen – occurs off the coast of Louisiana each year. This phenomenon is serious because most aquatic species cannot survive at low oxygen levels and it occurs in the middle of some of the Nation's most valued fisheries. A broad-scale integrated assessment of the causes and consequences

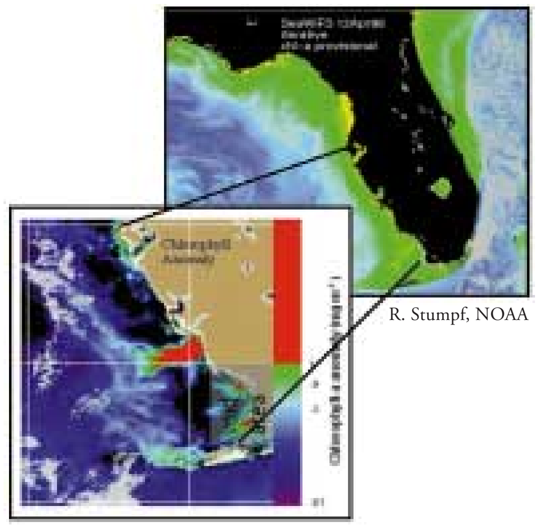


V. Bierman, Limno Tech, Inc.

This forecast of expected Gulf oxygen increases in response to nitrogen load reductions was a key component for reaching the Federal/State/Tribal agreement to reduce nitrogen loads from the Mississippi River Basin.

of that hypoxic zone concluded that excess nitrogen from the Mississippi River basin was the dominant cause. A key challenge then was to determine what load reduction was needed to significantly raise oxygen levels.

Harmful Algal Blooms (HABs) – lethal growths of algae – restrict harvests of fish, divert public funds to health and environmental monitoring programs, depress recreational and tourist industries, and can cause illness and even death in those who consume products from the sea. While they can occur naturally, HABs are found in every



R. Stumpf, NOAA

Combining satellite imagery of surface algae with information on ocean circulation and atmospheric conditions enables forecasts of bloom movement off Florida's west coast. State officials use these forecasts to monitor the bloom and warn the public.

coastal state and they appear to be increasing in frequency, duration, and severity. Forecasting HAB distribution and movements helps reduce these impacts by identifying where blooms are and allows early warning of shellfish and beach closures. Currently, we can predict where an HAB may come ashore in Florida once it has started, but further research is needed to predict when and where a bloom will develop.

Hantaviruses – diseases carried by rodents, especially the deer mouse – infect humans through exposure to rodent droppings. These viruses are potentially deadly, requiring immediate medical care once symptoms appear. Until recently, diseases caused by hantaviruses were thought to be restricted to Europe and Asia. But outbreaks

Rodents such as the deer mouse can carry hantaviruses. Forecasting increases in their abundance can aid in warnings about spread of the virus.

in the United States in 1993 proved otherwise. An understanding of the relationship between climate change, ecology, and natural pathogens enabled the development of predictive models for human infection and allowed forecasts of human risk. Improved understanding of such factors developed during and after the 1993 outbreak allowed researchers to accurately predict the hantavirus outbreak in the Southwest in 1997.

Asian Longhorned Beetle – an invasive species – poses a serious threat to hardwood trees in the United States. The beetle feeds deep within the tree, blocking water and sap movement, and eventually kills the tree. Models that combine information on the basic biology and ecology of a species with patterns of human activities that influence

If not controlled, the Asian longhorned beetle could become a major pest and have a significant impact on the lumber, maple syrup, nursery, commercial fruit, and tourism industries.

dispersal, such as urban and suburban land use and forest management practices, can be used to forecast likely patterns of establishment and spread.

"One of the most pressing challenges that the United States—and indeed, the world—will face in the next few decades is how to alleviate the growing stress that human activities are placing on the environment. The consequences are just too great to ignore... Yet, there is reason to have hope for the future. Advances in computing power and molecular biology are among the tremendous increases in scientific capability that are helping researchers gain a better understanding of these problems."

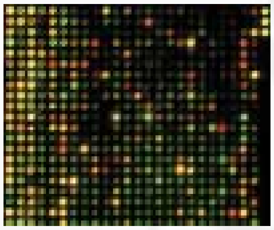
—Thomas Graedel
Yale University

New Era Possible Through New Science and Technology

Today, sophisticated ecological forecasting is a tantalizing possibility. But while there has been some progress, the promise of this maturing field lies on the horizon.

More to the point, a variety of recent developments have converged to offer us an historic opportunity to accelerate progress. Technological advances, particularly in computer science, telecommunications, remote sensing, genomics, ecological theory, and nanotechnology, offer us the very real chance to bring ecological forecasting to new levels. The ecological science community is entering a new era in which forecasts of ecological change can become commonplace if we bring to bear the new tools, monitoring and observing systems, and increased understanding available today and on the horizon.

The mass storage capabilities these systems embody will prove invaluable in providing access to data needed to drive and test ecological forecasts.



New data from gene/protein chips will provide invaluable information for building biological complexity into ecological forecasts.

Smart dust, packing the power of a PC into a speck of "dust," will allow scientists to monitor environmental change at very small scales.

The ecological science community is entering a new era in which forecasts of ecological change can become commonplace if we bring to bear the new tools, monitoring and observing systems, and increased understanding available today and on the horizon.

At the largest scales, for example, over the next 15 years, a series of Earth-observing satellites will collect data on an unprecedented scale via a series of satellites and field experiments. Data and information from these and other field experiments and observing systems, designed to develop and test relationships between satellite-based observations and Earth processes, will make possible ecosystem analyses at unprecedented scales. At the same time, networks of data centers will assemble, archive, and distribute the enormous amounts of data. Currently, robotic mass storage systems are managing hundreds of terabytes of information (a byte is the memory space needed to store 1 character; a terabyte is 1 trillion bytes). But over the next decade, thousands of times that amount will be collected and made available to individuals working around the world.

At smaller scales, another recent innovation holds great promise. "Smart dust" is composed of tiny computerized communicating sensors. These sensors, the size of particles of dust, can be scattered throughout the environment to send back information from their movements. For example, they are light enough that air currents can keep them aloft for lengthy periods of time. Applications already envisioned include checking the weather inside storms, warning jetliners of air turbulence, and detecting chemical weapons. Future "smart dust" research is aimed at imbuing significantly smaller particles with even greater communications capabilities and using these tiny sensors to communicate the dynamics of some of the smallest components of ecosystems.

At even smaller biological scales, new techniques from genetics research will help unravel complex biological and ecological processes. A genome is the complete complement of genes in an organism – its genetic instructions or blueprint for that species. Today we have identified and placed in order all the genes from several model organisms and have a rough draft of the human genome. Newly developed gene/protein chips (an innovation from biotechnology and nanotechnology) offer unprecedented opportunities to measure, monitor, and understand the complex structures and activities of living systems. This technology lets researchers monitor genetic diversity and simultaneous interactions among thousands of genes, and discover which genes are affected by various environmental changes.

Framing the Science Agenda

While innovative technologies will strengthen our ability to observe and track ecological change, advancements in understanding the fundamental processes underlying those changes are also critical. In addition to gathering new data and understanding ecological processes, techniques are also being developed for including those data and processes in models and for analysis of forecast uncertainty. Much of this is on the horizon in framing a science agenda for advancing ecological forecasts. This agenda is rooted in three themes:

Understand Ecosystem Composition, Structure, and Functioning. A new agenda is needed to respond to relevant recommendations in recent reports of the National Academy of Sciences, the President's Committee of Advisors on Science and Technology (PCAST), and the National Science Board. These include studies to improve understanding of the role of biological diversity in determining ecosystem resilience and in quantifying ecological scale interactions. We need to improve ways of modeling movement of nutrients, carbon, water, and other substances through biota, soil, sediment, water, and air, and of estimating how ecosystems respond to combinations of stresses at local and regional scales.

Monitor Ecosystem Status and Trends, and Make Complex Data Available. Ecological forecasts cannot be produced without reliable information about the current and historical condition of ecosystems. Likewise, the success of decisions made in response to specific forecasts cannot be evaluated without ongoing monitoring of change. Rapid advances in remote sensing and *in situ* sensing ("in the actual place"; contrasted with "remote") offer new opportunities to provide these data. However, new observation, modeling, and data management tools are needed to deal with gathering, integrating, and interpreting complex biological and chemical data, and making them available.


National Biological Information Infrastructure

PCAST spoke of the need to support development of a National Biological Information Infrastructure, a Web-based system for accessing and integrating biodiversity and ecosystem information. Such a system will be essential for ecological forecasts.

Develop and Improve Prediction and Interpretation Tools. A central challenge for ecological forecasting is to develop advanced tools for translating the rapidly increasing ecological knowledge base into information needed by decision makers. The combination of complex interactions among a large number of components with the variable nature of ecosystems and their driving forces, makes the development of such tools a significant challenge.

A new generation of Earth-observing satellites has ushered in the next generation of remote sensing technologies, offering significantly greater coverage, resolution, and range of measurement abilities than ever before. These technologies are opening new ecological observation windows – and new ecological forecasting possibilities.

Collaboration is the Key

The basis of scientific predictions is good data and information and a solid understanding of natural processes. Strong collaboration among Federal agencies, with the academic community, and with the private sector, is essential for ensuring development of ecological forecasting capabilities.

Accomplishing this will be a challenge, but it is not beyond our reach. It will unfold over time as its assumptions and ideas are tested. With that in mind, our agenda is purposeful — but flexible. We invite you to help us shape it.

Now, at the beginning of the 21st century, we are poised to capitalize on new opportunities as we significantly change the way we anticipate and manage ecological risk.

For More Information

For more information and a copy of the interagency concept plan, you can contact: <EcologicalForecasting@si.edu>.

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