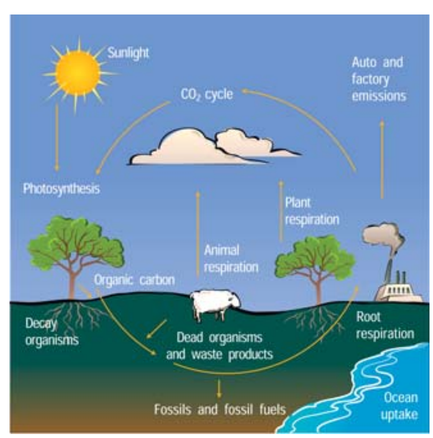
Life

If climate had no significant impact on Earth's ecosystems and living things, climate change would be a mere curiosity of planetary science. Instead, we know that ecosystems evolved in concert with predictable annual weather patterns for survival. Changing weather patterns affect where plants can grow and where animals can thrive. Even small changes in climate can tip the delicate balance of competition and cooperation among the residents of an ecosystem. The potential for climate change to disrupt life on Earth makes studying it essential.

Several male narwhals in Inglefield Bredning, West Greenland, 2002. Narwhals rely on Arctic sea ice cover for their hunting behaviors, and may not be able to adapt to an ice-free Arctic Ocean. *Credit: Courtesy of Mads Peter Heide Jørgensen, NOAA*

Earth's ecosystems are not only affected by climate, they also play a major role in influencing global climate. Living things regulate the composition of the atmosphere. Plants use carbon dioxide (CO_2) to grow and produce oxygen; when plants die, microbes break them down into the organic matter of soil, methane gas, CO_2, and other byproducts. Changes in land use or average temperature can disrupt an ecosystem's cycling and storage of carbon, creating the potential for large amounts of CO_2 or methane to be released into the atmosphere. Earth's forests, marine



This diagram shows the carbon cycle. All life is based on the carbon atom, which can exist in solid, liquid, or gas form. Carbon constantly moves through all living things, as well as through the oceans, atmosphere, and Earth's crust. Carbon dioxide in the atmosphere plays a vital role in regulating air temperature on Earth. *Credit: © University Corporation for Atmospheric Research*

Top image credit: © Forrest Brem, courtesy of NatureServe environments, wetlands, tundra, and other habitats store vast amounts of carbon. Land cover and the choices humans make about determining where plants will grow can have a profound impact on both regional and global climate. Understanding the biological processes involved in the carbon cycle is essential to predicting future climate, and efforts are currently under way to incorporate living systems into global climate models.

NSF supports biologists as they seek a greater understanding of what a warmer global climate means to life on Earth. NSF supports 63 percent of the fundamental environmental biology research at U.S. academic institutions, fostering advances in the biological sciences through research grants and providing the infrastructure to enable those advances.[1]

The urgency of this research comes sharply into focus when we realize that our own species is highly dependent on Earth's ecosystems. Living organisms do much more for us than provide food, clothing, and shelter. Plants are not only responsible for the very oxygen we breathe; they help regulate the temperature and moisture of the places we call home. Plant roots prevent topsoil from eroding away or burying our houses. Forests of swaying trees and acres of wetlands literally calm storms by dissipating wind and wave energy. Microorganisms decompose our garbage and help us digest our food. Without the ecosystems of the world, big and small, our existence would be impossible.

Long-Term Ecological Research

To understand how climate change affects an ecosystem, continuous observational records of that ecosystem are necessary. For more than 25 years, NSF has steadfastly supported the Long-Term Ecological Research (LTER) Network, a collaborative effort currently involving more than 1,800 scientists and students studying ecological processes at sites strategically located around the United States, Puerto Rico, Tahiti, and Antarctica. The 26 LTER sites are windows to global change.

Autumn colors, with the Brooks Range in the background, near the Sagavanirktok River, Alaska. This area is part of the Arctic Long-Term Ecological Research (Arctic LTER) site. *Credit: Jim Laundre, Arctic LTER*

As observatories, they document long-term changes in plants, animals, microbes, and soils in relation to short-term weather and long-term climate changes. LTER sites illuminate interactions among the physical, chemical, and biological components of ecosystems through controlled experiments and long-term observations. These sites allow comparisons of the relative sensitivity of populations, communities, and ecosystems to environmental change. The synthesis and modeling of data from LTER sites enable predictions of feedbacks, both positive and negative, on global change. Research at LTER sites spans the range from relatively less managed landscapes, such as Arctic tundra, to intensively managed cities and farmlands.[2]

National Ecological Observing Network

In response to the ecology research community's recommendations for a new approach to studying the biosphere, NSF implemented the planning phase of an ecological observing network with the unprecedented ability to study the complex phenomena driving ecological change. The National Ecological Observatory Network (NEON), a regional-to-continental scale network, will help us understand the impacts of climate change, land-use change, and invasive species on ecology. NEON will gather data on ecological responses of the biosphere to changes in land use and climate, and on feedbacks with the atmosphere, water cycle, and other natural and human systems.

1 NSF FY 2009 Budget Request to Congress: www.nsf.gov/bio/budget/fy09/neon09.pdf.

2 Global Change Research, LTER Net: www.lternet.edu/global_change.

NEON is a single national observatory, not a collection of regional observatories. It will consist of a seamlessly linked, distributed network of sensors and experiments, connected by advanced cyberinfrastructure. Using standardized protocols and an open data policy, NEON will record and archive essential data for developing the scientific understanding and theory required to manage the nation's ecological challenges.[3]

NEON infrastructure will include instrumented towers and sensor arrays, remote sensing capabilities, cutting-edge laboratory instrumentation, natural history archives, and facilities for data analysis, modeling, visualization, and forecasting—all networked onto a cyberinfrastructure backbone. The information gathered from NEON will be the best and most complete picture we have of the ecological changes taking place across the continent and will prove invaluable to climate modelers and policymakers.[4]

Species Adaptation

In field studies, biologists are encountering change in nearly every ecosystem they study, and some species seem especially susceptible to the effects of a warmer climate. Polar bears are one famous example of a species that seems particularly vulnerable to warming. The sea ice they require to access Arctic ringed seals (a primary source of food) is melting, diminishing their hunting range. Even if polar bears are able to adapt to a warmer, land-based lifestyle, competition, potential hybridization with grizzly bears, and increased human interactions would present significant challenges to the species' survival.[5]

NSF-supported researchers have documented other species at risk, including many of the world's amphibians. Results from an NSF-funded study provide the first evidence of a link between climate change and outbreaks of an infectious disease that has wiped out dozens of tropical frog populations.[6] Other NSF-funded researchers have compiled the latest information on the distribution and diversity of more than 4,000 mammal species to analyze the risk of extinction owing to threats including global climate change.[7] This type of information can identify "hotspots" of endangered species, helping conservationists decide how to best allocate their resources.

While some species seem destined for extinction because of rapid climate change, other species are providing researchers with unprecedented examples of evolutionary biology in action. Numerous NSF-funded researchers have

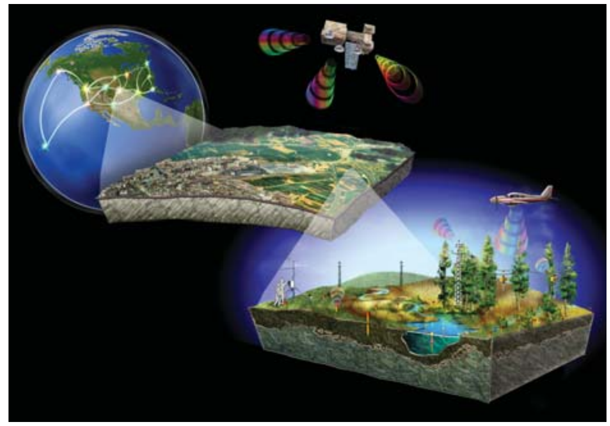
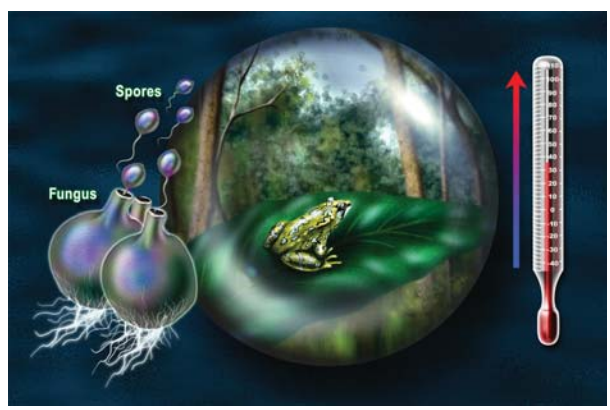


Illustration of the National Ecological Observatory Network (NEON). NEON will incorporate a variety of land-, air-, and satellite-based sensors and monitoring equipment, linked by an extensive network of cyberinfrastructure. *Credit: Nicolle Rager Fuller, National Science Foundation*

Polar bears depend on the presence of sea ice in the Arctic for access to their main prey, seals. Scientists are concerned that diminished summer sea ice in the Arctic threatens polar bears' survival. *Credit: © 2009 JupiterImages Corporation*



Recent studies show that Earth's warming climate is contributing to the increase of chytrid disease, a fungus infection that is responsible for the extinction of many tropical frog species. The fungus, *Batrachochytrium dendrobatidis*, infects tadpoles and eventually attacks the skin of adults and kills them. Scientists know the spore stage can swim through water to infect other frogs, but there is still much to know about how the disease spreads and whether it can survive in other animals. *Credit: Nicolle Rager Fuller, National Science Foundation*

3 NEON overview: www.neoninc.org/about-neon/overview.html.

4 NSF-Supported Research Infrastructure: Enabling Discovery, Innovation, and Learning, 2008.

5 ACIA, *Impacts of a Warming Arctic: Arctic Climate Impact Assessment*, Cambridge University Press, 2004, p. 58.

6 NSF Highlight 15975: Climate Change Driving Amphibian Extinctions.

7 NSF Highlight 13166: Predicting the Next Mammals at Risk.

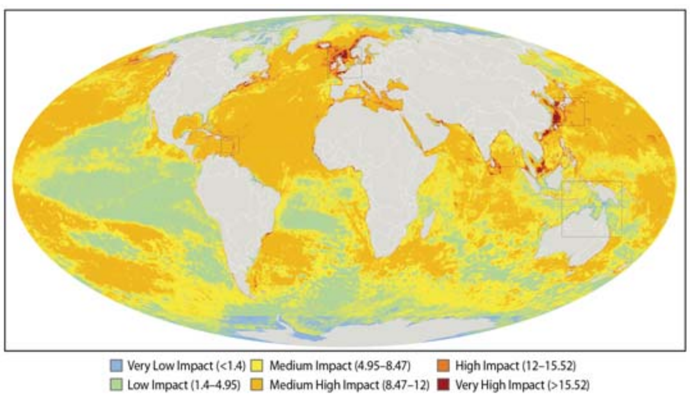
documented genetic shifts in natural populations resulting from climate change. These studies suggest that extreme variation in temperature and rainfall are selecting for genetic shifts in organisms with life spans short enough to allow some adaptation at the current rate of climate change. In one example, the rise of drought conditions in southern California selected for a genetic shift in populations of field mustard plants (a common weed). Plant populations exposed to several years of drought bloomed sooner, increasing their chances of reproducing before drying out from a lack of rain.

In another example, researchers found genetic shifts in fruit flies that correspond to temperature increases. Researchers compared genetic evidence collected almost 30 years ago from wild fruit flies with the genetic profiles of present-day fruit flies. They found that flies at higher latitudes have the chromosomal characteristics associated with the low-latitude flies in the original study. The low-latitude chromosome changes are thought to protect the flies from warmer temperatures; thus, the flies appear to have undergone genetic adaptation to warmer temperatures.[8] Genetic changes attributed to global warming-related seasonal changes have also been observed in populations of migrating birds, mosquitoes, and other species.[9]

In addition to genetic adaptation, rising temperatures and CO_2 levels can influence gene expression. In a recent study, NSF-supported researchers demonstrated that flowering plants grown in the elevated CO_2 levels projected by current climate models bloomed significantly later than equivalent plants grown at modern atmospheric CO_2 levels. This research has important implications for predicting the future behavior of plant and crop species.[10]

National Center for Ecological Analysis and Synthesis

The NSF-funded National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California-Santa Barbara is a leading example of the kind of interdisciplinary collaboration we can expect to see much more of in the years ahead. Ecologists work with specialists in allied fields to address major fundamental issues in ecology and their application to management and policy. The center focuses on developing and testing important ecological ideas and theories using existing data. Working in teams, NCEAS researchers focus on analyzing ecological information with cutting-edge approaches, accessing and using data, promoting the use of sound science in policy and management decisions, investigating sociological issues that pertain to the science of ecology, and educating with sound ecological principles.[11]



According to a study conducted by the National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California-Santa Barbara, more than 40 percent of the world's oceans are heavily affected by human activities, and few, if any, areas remain untouched. *Credit: NCEAS*

NCEAS projects examine issues such as climate change and forest pathogens, global climate change and adaptation of conservation priorities, biodiversity, and many other topics relevant to ecosystems and climate change.[12] This research has provided insight into a variety of complex ecosystem issues.

In examining the effects of human activities on the sea, researchers at the NCEAS produced a detailed map of the world's oceans, providing policymakers with a clear and unmistakable view of the dramatic effects of climate change, overfishing, and pollution on the world's oceans. The research team found that more than 40 percent of the world's oceans are heavily affected by human activities, and virtually no marine region remains untouched by humans.[13]

8 NSF Highlight 13082: Genetic Consequences of Climate Change.

9 NSF Highlight 15953: Climate Change: A Driver of Evolution.

10 NSF Highlight 16828: Is There a Relationship Between Global Climate Change and Flowering?

11 NCEAS Web site: www.nceas.ucsb.edu/overview.

12 NCEAS Working Groups: www.nceas.ucsb.edu/research/wg.

13 NSF Highlight 16039: First-Ever Global Map of the Influence of Total Anthropogenic Activities on the Marine Ecosystem.

Life in the Sea

One of the ocean's most important and diverse ecosystems may be one of the most sensitive to changes in temperature and ocean chemistry. Coral reefs provide habitats for a large variety of plant and animal species. As physical structures, they reduce the destructive impact of ocean surges during storms. NSF researchers are studying corals to learn how resilient they may be to changing ocean conditions. In a recent study, scientists found that bleaching events occur when rising ocean temperatures cause the coral to expel the symbiotic algae that give coral their distinctive colors. The researchers discovered that this is a coping strategy for the stressed animals. Coral can survive periods of bleaching by consuming zooplankton from the surrounding water, indicating that some coral may be able to survive future periods of elevated sea temperatures.[14]

Corals like these on the undersea Stetson Bank in the Gulf of Mexico are affected by the increasing acidity of the oceans. *Credit: Frank and Joyce Burek*

Bering Ecosystem Study

The Bering Sea hosts one of the most ecologically rich and economically productive food chains in the world, producing more than 50 percent of the U.S. fish and shellfish catch.[15] Its location in the climate-sensitive Arctic region means that the effects of global warming may have a significant impact on the organisms that call the Bering Sea home. In partnership with the North Pacific Research Board, NSF launched the Bering Ecosystem Study (BEST) to improve our understanding of the effects of climate variability on the Bering Sea marine ecosystems, including the social implications of climate change and the role of human activities in the system. BEST will examine such factors as diminishing sea ice, decreasing ocean salinity, and shifting plankton availability in the Bering Sea.[16]

Steller's Sea Lions, Amak Island, Alaska. Large Arctic marine mammals are an important part of the Bering Sea ecosystem. *Credit: Kevin Bell, U.S Fish and Wildlife Service*

Conclusion

Life on Earth has a direct and profound effect on global climate; it is a vital link in the carbon chain. Ecosystems such as forests regulate the flow of heat and moisture in a region, contributing to local climate patterns. The climate models of the future will have to account for the effects of living things to produce accurate climate forecasts. Living things are vulnerable to climate change; in a warming world, plants and animals will face significant changes in their habitats. Some species have already demonstrated the ability to adapt to a changing climate, but we do not yet have a full understanding of the implications of anthropogenic climate change on the planet's plant and animal species. Long-term environmental observations, fieldwork, and statistical analyses of ecosystem data have yielded important information about the effects of climate change on the biosphere. In the research highlights below, numerous NSF-funded life research projects are described. These projects have all contributed to our understanding of how life on Earth is both influencing and influenced by climate change. This research also provides invaluable experience and training to the next generation of life scientists.

14 NSF Highlight 13490: Coral Reef Bleaching: A Novel Strategy for Survival.

15 Bering Ecosystem Study Science Plan, Fairbanks, Alaska: Arctic Research Consortium of the United States, 2004, p. 9.

16 ARCUS BEST Web site: www.arcus.org/bering/index.html.

Global Warming Linked to Amphibian Extinction

The Panamanian golden frog *(Atelopus zekeki)* is a member of the harlequin frogs (Genus: *Atelopus*). Scientists estimate that about 67 species of harlequin frogs have gone extinct due to fungus outbreaks. Evidence links these outbreaks with climate change. *Credit: © Forrest Brem, courtesy of NatureServe*

Global warming is causing outbreaks of an infectious disease that is wiping out entire frog populations and driving many species to extinction, according to results from an NSF-funded study. The study reveals how warming may alter the dynamics of a skin fungus that is fatal to amphibians. The climate-driven fungal disease, the authors say, has hundreds of species around the world teetering on the brink of extinction, or has already pushed them into the abyss.

In the remote mountainous areas of Costa Rica, the Monteverde harlequin frog (*Atelopus* sp.) and the golden toad (*Bufo periglenes*) have not been seen since the 1980s, and are considered extinct by authorities. The loss of these tropical species sent alarm and suspicion throughout the scientific community. Today, almost 70 percent of the 110 species of the colorful *Atelopus* frogs endemic to the Americas have gone extinct as a result of a lethal fungus (*Batrachochytrium dendrobatidis*). Using records of sea surface and air temperatures, researchers have provided evidence that harlequin frogs are disappearing in near lockstep with changing climate. According to the scientists' hypothesis, Earth's rising temperatures enhance cloud cover on tropical mountains, leading to cooler days and warmer nights, both of which favor the chytrid fungus.

The study results come at a time of growing concern about the future of amphibians. The Global Amphibian Assessment, published in 2004, found that nearly one-third of the world's 6,000 or so species of frogs, toads, and salamanders face extinction from a variety of causes—a figure far greater than that for any other group of animals. **Highlight ID: 12013 BIO/DEB**

Predicting the Next Mammals at Risk

Polar Bears were recently listed as "vulnerable" by the World Conservation Union (IUCN). *Credit: © 2009 JupiterImages Corporation*

Although news of rising temperatures and disappearing ice sheets has foreshadowed the recent addition of the polar bear to lists of vulnerable species, not all species are associated with such dramatic warning signs that they are in danger. A new database is allowing researchers to use detailed data to determine optimal strategies for conserving species that are threatened now and to predict those that may be at risk in the future.

This novel NSF-funded work, led by John Gittleman of the University of Virginia, combined the latest information on the distribution and diversity of more than 4,000 mammal species with exceptionally fine-scaled maps of their ranges. Aggregating such large amounts of geographic information required collaboration with mammalian experts worldwide and the development of new computer software that permitted an overlay of thousands of maps. Through this synthesis, researchers were able to elucidate how range size could combine with certain ecological, morphological, and life-history traits (e.g., large body size, long gestation) to increase the risk of extinction for particular species. They used information on current risk factors combined with predictive models to identify geographic areas that currently have the highest potential for future species losses. Although regional patterns of species richness became apparent when the mammalian ranges were compared with those of other vertebrates, local hotspots of rarity for mammals were largely nonoverlapping with areas that were important for birds and amphibians. **Highlight ID: 13166 BIO/DEB**

Genetic Consequences of Climate Change

Recently, multiple NSF-funded researchers have documented genetic changes resulting from climate change. These studies suggest that extreme variation in temperature and rainfall are causing genetic shifts in organisms with short life spans.

At the University of California-Irvine, Arthur Weis is studying how a 5-year California drought caused genetic changes in field mustard, a weedy plant that is common throughout the United States. Weis collected seeds from wild plants before and after the drought, then raised them under identical conditions to observe differences between the two samples. Even when provided with sufficient amounts of water, plants grown from postdrought seeds bloomed sooner. During the drought, natural selection favored this particular trait because it allowed the plants to seed successfully before conditions became fatally dry. Building on this study, Weis is organizing an NSF-funded workshop to stimulate a concerted scientific effort to collect and preserve seeds across North America. Called Project Baseline, this undertaking will provide scientists with an important resource for studying future climate change–induced evolutionary events.

On a global scale, Raymond Huey of the University of Washington and George Gilchrist of the College of William and Mary have found genetic changes in fruit flies that correspond to temperature increases. In their study, they examined a certain type of genetic change known as a chromosomal inversion. More than 40 years ago, scientists documented these genetic rearrangements in wild populations of the fruit fly species *Drosophila subobscura* and noted that the frequency of the inversions correlated with the flies' latitude. Although the exact purpose of the inversion is unknown, it appears to protect the flies against warm temperatures. Huey and Gilchrist used the past data and added information on present-day fruit flies on three continents. Their analysis shows genetic differences between contemporary fruit flies and 1981 populations: Flies at higher latitudes have more of the low-latitude chromosomal inversions. In other words, these flies have undergone genetic adaptation to warmer temperatures. **Highlight ID: 13082 BIO/DEB**

Climate Change: A Driver of Evolution

Climate change has resulted in heritable genetic changes in species as diverse as birds, squirrels, and mosquitoes, and in traits such as range limits, reproductive patterns, dormancy, and migration. Because the most obvious facet of climate change is increasing temperatures, it is tempting to simply attribute these genetic changes to higher temperatures. However, many species use day length as a critical cue, and changing temperatures can lead to a mismatch between those cues and environmental conditions. As discussed by William E. Bradshaw and Christina M. Holzapfel of the University of Oregon in a recent publication, scientists are discovering that adaptation to changes in day length and the timing of growing seasons can be important when species adapt to climate change.

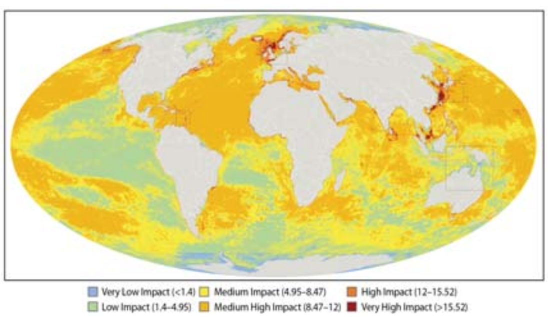
In a study involving the pitcher-plant mosquito, Bradshaw and colleagues experimentally raised mosquitoes from a northern population in a simulated southern climate with shorter days. The mosquitoes laid fewer eggs— 88 percent of the loss was due to transplanted mosquitoes experiencing the incorrect day length relative to temperature. As climate change occurs, many species in the Northern Hemisphere will migrate northward to avoid increasing heat stress. However, species for which day length is an important determinant of development and reproduction will have to adapt to the new day length to avoid a mismatch. This study emphasizes the complex nature of global change and the need to understand how many aspects of that change will interact with organisms and their evolution.

Bradshaw and Holzapfel note that evolutionary adaptation to rapid, human-caused climate change is only likely to occur in small animals with short life cycles and large population sizes, because those are conditions that allow fairly rapid evolution. Large animals with long life cycles and smaller population sizes may have no options but to migrate to cooler climates, suffer declines in population size, or simply be replaced by species from historically warmer climates. Though researchers are still examining exact mechanisms and rates of evolutionary change, it is widely recognized that climate change will dramatically modify our natural communities. **Highlight ID: 15953 BIO/DEB**

Is There a Relationship Between Global Climate Change and Flowering?

From a survey of past studies, researchers at the University of Kansas knew that rising carbon dioxide (CO_2) exerts a strong effect on flowering time in the majority of plant species, although the mechanisms for this response are not yet well understood. Using *Arabidopsis thaliana*—a small flowering plant with a relatively short life cycle—the researchers have, for the first time, demonstrated that elevated CO_2 can influence the expression of genes involved in the initiation of flowering. Specifically, they found that the gene *Flowering locus C* plays a large role in determining delayed flowering in plants grown at elevated CO_2 levels. By describing these specific mechanisms, scientists are in a better position to predict the future responses of plants to a changing environment and to determine the best approach for improving crop responses to increasing CO_2 concentrations of the future. **Highlight ID: 16828 BIO/IOSz**

First-Ever Global Map of the Influence of Total Anthropogenic Activities on the Marine Ecosystem



Marine ecosystems worldwide have been widely affected by human activities. *Credit: NCEAS*

More than 40 percent of the world's oceans are heavily affected by human activities, according to the first-ever global scale study of anthropogenic impact on marine ecosystems. Research conducted by Fiorenza Micheli of Stanford University and John Bruno of the University of North Carolina-Chapel Hill, and analyzed at the National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California- Santa Barbara (along with several other researchers from a broad range of universities, nongovernmental organizations, and government agencies), describes the gravity of the global human impact of marine ecosystem changes. The researchers overlaid maps of 17 different factors of human activity, such as fishing, pollution, and commercial shipping, to produce a composite map of the toll that humans have exacted on the oceans. They also included effects of anthropogenic climate change such as ocean acidification, increased ultraviolet radiation, and ocean temperature. They found that no region is unaffected by human activity but that large regions with relatively little human impact remain, particularly near the poles. They also found that different ecosystems were affected differently. Hard- and soft-bottom continental shelves and rocky reefs have the highest predicted cumulative impact scores, while open oceans and deep waters have the lowest. Analyses of this type will provide valuable tools for regional and global efforts to allocate conservation resources and for informing ecosystem-based management. **Highlight ID: 16039/ Press release 08-024 GEO/OCE**

Coral Reef Bleaching: A Novel Strategy for Survival

See *Sea* section
Highlight ID: 13490 GEO/OCE

Germ Bath Helps Amphibians Fight Off Fungus

Batrachochytrium dendrobatidis, a deadly pathogenic fungus, is causing population declines and extinctions in many amphibian species around the world. NSF-funded researchers may have discovered a potential solution: Inoculating amphibians with certain bacteria helps the amphibians fight the infection.

Scientists believe that amphibians are becoming more susceptible to *B. dendrobatidis* because of increased stress caused by pollution and climate change. Reid Harris of James Madison University and his colleagues isolated different bacterial species from the skin of a common salamander and placed each species on *B. dendrobatidis* growing in a Petri dish. Harris and his colleagues then allowed red-backed salamanders to swim in a bath of these bacteria for 2 hours, then infected them with the lethal fungus. When investigated 18 days later, the salamanders given the bacterial bath were nearly 30 percent more likely to have rid themselves of the fungal infection than those that were not treated.

Harris suggests that adding fungus-fighting bacteria to ponds or sites frequented by threatened amphibians might reverse some of the population decline. The population decline of amphibians worldwide has baffled scientists for decades. This study offers a glimmer of hope for dealing with the crisis. **DEB Climate Change Report highlight**

Long-Term Ecological Research Program to Examine Effects of Sea-Level Rise on South Florida

One of the Florida Coastal Everglades Long-Term Ecological Research sampling stations is located on the edge of the forest (center of photo). *Credit: Victor H. Rivera-Monroy and Robert R. Twilley, FCE LTER Program and LSU*

In the Everglades, climate change manifests primarily through sea-level rise and hurricanes. Sea-level rise, coupled with dramatically reduced freshwater inflows to Everglade estuaries in the past century, has led to the landward retreat of mangrove wetlands. Hurricane storm surges across this very flat landscape accelerate the landward transgression.

Sea-level rise also leads to saltwater intrusion of the shallow Biscayne Aquifer that supplies more than 6 million people with freshwater. Thus, both sea-level rise and changes in the frequency and intensity of storms threaten the long-term sustainability of freshwater supply to a growing human population. In the face of these threats, restoration projects are seeking ways to increase freshwater flows to the coastal Everglades. Restoration may temporarily slow the landward encroachment of sea-level rise and enhance recharge of the critical Biscayne Aquifer; however, long-term consequences of climate change owing to sea-level rise confound the potential outcome of restoration.

New research at the Florida Coastal Everglades Long-Term Ecological Research Program is integrating social and natural science to assess the complex interactions of Everglades restoration, land-use changes driven by a growing human population, and water supply issues. The importance of this integrated research approach is addressed regularly in the news by increasing reports of hurricane landfalls, with Hurricanes Katrina and Rita as the most recent and dramatic examples. **DEB Climate Change Report highlight**

Sea-Level Rise Threatens Mangrove Forests

Sea-level rise threatens a host of coastal ecosystems, including mangrove forests. Throughout the tropics, these ecosystems are situated between land and sea, and offer key ecological and societal benefits, including providing nursery and refuge habitat for

Ground view of Twin Cays, Belize, showing dwarf red mangroves *(Rhizophora mangle)* that are estimated to be more than 100 years old. These pygmy stands are common in the interior of oceanic islands in the Caribbean and are an important habitat for a variety of organisms. However, such areas are commonly targeted for development. *Credit: K.L. McKee* commercially important fish species, buffering land against hurricanes and tsunamis, preventing land erosion, and filtering sediment from land runoff water before it reaches sensitive sea grass and coral reef ecosystems. In order for many of these bordering ecosystems and the hundreds of species they contain to be healthy or even to exist, mangroves are necessary.

Mangrove ecosystems function in building land by collecting sediment and debris in their tangled roots. NSF-funded scientist Karen McKee of the United States Geological Survey examined the capacity of mangrove ecosystems to maintain soil elevations, relative to sea-level rise, by investigating the mangrove forest's natural function and ability to vertically build sediment deposits through trapping organic matter. McKee found that mangroves throughout her sites in Central America could tolerate rates of sea-level rise of up to 4 millimeters per year. Rates of rise in McKee's sites are predicted to be between 7 and 8.5 millimeters per year, and most model global sea-level rise scenarios are projected at rates of 3–5 millimeters per year.

McKee's work suggests that many mangrove habitats throughout the world may not be able to keep up with the currently predicted rates of sea-level rise. Mangrove ecosystems may also expand landward in response to sea-level rise, yet many locations may be unavailable to mangroves because of natural and human barriers. Loss of mangrove vegetation would halt soil accumulation and encourage land erosion, leading to further submergence and loss of land to the seas. **DEB Climate Change Report highlight**

Positive Feedback: New Plant Growth in Tundra Causes Further Warming

Arctic tundra wildflowers in bloom. *Credit: U.S. Fish and Wildlife Service*

Some climate-induced changes themselves affect the climate. Such a loop of causation is called feedback. In ecosystems demonstrating positive feedback with a warming climate, the initial effects of climate on the ecosystem result in changes that contribute to further warming. These changes alter primary production and nutrient cycling, and transform habitat for native species that have existed in these biomes for millennia. Vegetative changes are expected to be extensive owing to climate change, particularly in Arctic tundra habitats. The Intergovernmental Panel on Climate Change estimates that warming may result in the loss of as much as 40 percent of current tundra by the year 2100; it will be replaced by boreal forest.

An NSF-supported project involving M. Syndonia Bret-Harte from the University of Alaska, Fairbanks, examined the loss of pristine tundra habitat and its relation to climate change. While other studies have investigated this issue, many have used dissimilar methods, confined to small study areas and short time periods, inhibiting the scientists' abilities to infer wide-ranging effects. However, NSF-funded investigators, as part of a network of scientists identified as the International Tundra Experiment, examined plant community responses at 11 tundra locations throughout the world.

The study demonstrated that even moderate increases in temperature caused significant changes in tundra vegetation, as vascular plants grew significantly taller under warming. These rapid changes occurred after only two growing seasons. Scientists observed increased leaf density and a shift from herbaceous to woody plant growth. Greater leaf density in this traditionally frigid and relatively sparse, shrub-dominated ecosystem will likely amplify atmospheric warming by increasing the total amount of absorbed sunlight. **DEB Climate Change Report highlight**

Poison Ivy to Become More Toxic and Abundant Owing to Rising CO_2 Levels

Upon exposure to poison ivy *(Toxicodendron radicans)*, 80 percent of humans develop symptoms of dermatitis. Abundant in North America, this plant has been introduced in Europe and South Africa, and is invasive in Australia and New Zealand. *Credit: Courtesy of Jacqueline Mohan*

An NSF-funded study points out that 80 percent of all humans develop symptoms of dermatitis upon exposure to poison ivy (*Toxicodendron radicans*). It is one of the most widely reported ailments at poison centers in the United States. Abundant in North America, the plant has been introduced in Europe and South Africa, and is invasive in Australia and New Zealand. Because of its wide distribution and response to increased global atmospheric carbon dioxide (CO_2) levels, poison ivy presents a global public health concern.

NSF-funded researcher Jacqueline Mohan of the Ecosystems Center at the Marine Biological Laboratory conducted a 6-year study at the Duke University Free-Air CO_2 Enrichment experiment in which she assessed the impacts of elevated atmospheric CO_2 on growth and survivorship of poison ivy in an intact forest. Mohan also examined the effect of CO_2 levels on urushiol, the irritating chemical produced by poison ivy.

Mohan demonstrated that CO_2 enrichment increased photosynthesis and the efficiency of plant water-usage, and stimulated growth of poison ivy during the five growing seasons. Increased CO_2 levels increased the concentration of unsaturated urushiol by 153 percent, making the plant much more potent. Increased abundance of woody vines such as poison ivy is "choking" forests, causing tree mortality and slowing tree regeneration. These findings indicate that under projected levels of atmospheric CO_2, poison ivy may grow larger, more abundant, and more noxious than it is today.
DEB Climate Change Report highlight

Tropical Forests Affected by Climate Change

This image shows cloud forest vegetation immersed in fog, which is a relatively frequent and persistent climatic phenomenon in these ecosystems. *Credit: Martin Gomez-Cardenas, Iowa State University*

Climate change poses a considerable threat to tropical forests throughout the world. NSF-funded scientists have studied the effects of climate change on small plants growing directly on trees in tropical cloud forests. These plants, called epiphytes, act as "capacitors" to regulate seasonal precipitation because they absorb water and nutrients captured from rain and fog. The projection of reduced cloud water in tropical montane forests threatens these plants.

As a result of climate change, cloud water is predicted to decline in tropical montane forests. Nalini Nadkarni of Evergreen State College investigated the consequences of this reduction on epiphytes. In her work, Nadkarni transplanted epiphytes to lower elevations with less cloud cover, thereby simulating the unfavorable conditions that are predicted. Her results suggest that climate change will cause decreased epiphyte growth and leaf production, as well as increased mortality.

The loss of epiphytes will have consequences for ecosystem biodiversity, productivity, and resilience, because these plants provide the habitat and resources to support a rich assortment of species within the forest canopy. Because so many species rely on epiphytes, their loss would have a cascading affect that would threaten many of the plants and animals that inhabit the canopy. The reduced cloud cover will reduce the amount of canopy-held soil, which could make the ecosystem changes permanent.
DEB Climate Change Report highlight

Long-Term Study Leads to Elegant Understanding: Nitrogen Cycling

NSF researchers have simplified a previously complicated understanding of nitrogen release from decaying plants into the soil, making important contributions to global modeling of nitrogen and carbon cycles. The Long-Term Intersite Decomposition Experiment Team (LIDET), led by William Parton of Colorado State University, found that the amount of nitrogen released by bacteria as they decompose fallen leaves and dead roots is controlled universally by two factors: the initial concentration of nitrogen in the organic matter and the mass of the organic matter remaining. This information was used by LIDET to develop simple equations to model nitrogen release.

Because the controls for nitrogen release are the same at nearly every biome, modelers can use Parton's equations to improve global climate change models. Understanding global nitrogen cycling is important, because the release of nitrogen from decaying matter by bacteria and fungi in the soil provides ammonium and nitrate to plants. Ammonium and nitrate, inorganic forms of nitrogen that are essential to plant growth, are often in short supply to plants and therefore limit plant growth. An improved understanding of the role of nitrogen release in decaying matter will help scientists understand plant growth, and therefore carbon uptake, in global climate models.

The researchers were able to develop a global understanding of nitrogen release as they repeated the same decomposition study at 21 sites encompassing diverse ecosystems ranging from tropical forests to tundra. After 10 years of measurements, the researchers synthesized their data using resources at the National Center for Ecological Analysis and Synthesis (NCEAS), a center funded by NSF that develops and tests important ecological ideas and theories using existing data. Through the work at NCEAS, LIDET found that the release of nitrogen was controlled by the same factors at nearly all of their sites. They were able to use this information to develop a simple and elegant set of equations of nitrogen release. **Highlight ID: 14053 BIO/DEB**

Nitrogen: The Fertilizer of Climate Change Modeling

Predictions about the effects on climate from increases in atmospheric carbon dioxide concentrations have been hampered by our inability to quantify how much carbon will be sequestered by the terrestrial biosphere. Carbon sequestration—the removal of carbon from the atmosphere and storage via biological or geological processes—has the potential to slow the rate of global warming. Scientists are seeking to understand how terrestrial ecosystems will respond to the increased availability of carbon and warmer conditions forecast by current models.

In a recent study, NSF-funded scientist Edward Rastetter and his colleagues linked carbon sequestration to the forms of nitrogen in an ecosystem. This enabled them to identify the availability of organic versus inorganic nitrogen for the chemical reactions driving biological processes such as plant growth. Using a simple model of carbon-nitrogen interactions in terrestrial ecosystems, they found that the available form of nitrogen was not important for short timescales (less than 60 years); however, over longer timescales (more than 60 years), rates of carbon sequestration were linked to the amount and form of nitrogen that had accumulated in the ecosystem. Specifically, they determined that losing organic nitrogen from the system works against carbon sequestration in the long term. **Highlight ID: 11655 BIO/DEB**

What Happens When Permafrost Melts?

Permafrost that has not melted provides a solid foundation that holds trees upright. When permafrost melts, as it has here, the layer of loose soil deepens and trees lose their foundations, tipping over at odd angles. Siberians call these "drunken forests." Permafrost collapse in peatlands results in the slumping of the soil surface and flooding. This will be followed by a complete change in vegetation, soil structure, and many other important aspects of these ecosystems. *Credit: NASA photograph courtesy Jon Ranson, Goddard Space Fight Center*

Recent findings from an NSF-supported study suggest that warming in Arctic peatlands may not always increase the greenhouse gases responsible for global warming. Scientists have predicted that as rising atmospheric temperatures accelerate rates of permafrost melting, organic matter stored in this frozen peatland soil will decompose and release even more greenhouse gases (e.g., carbon dioxide and methane) into the atmosphere. However, Kelman Weider of Villanova University and his team found that while warming leads to permafrost melting, it also increases the growth of mosses that take up carbon from the atmosphere. These scientists found that the extent to which vegetation responds to changed climate has important feedbacks to Earth's climate system.

Peatlands form slowly as decayed vegetation collects over permafrost. Over time, these boreal wetlands have stored billions of tons of carbon-rich plant material. In Weider's 5-year study, researchers used field measurements, aerial surveys, and other methods to monitor changes in carbon storage and methane emissions.

During this research, the investigators also studied soil cores from the peatlands. These cores can tell the climatic and ecological history of the ecosystem. The peatland cores suggest that as the permafrost continues to degrade and the peatland begins to dry, slower growing plants will replace the water-loving, fast-growing mosses. Thus, current rates of carbon uptake resulting from moss growth may compensate for greenhouse gas releases. **Highlight ID: 15255 BIO/DEB**

Effects of Global Warming on Trees and the Insects That Eat Them

By altering foliage quality, exposure to elevated levels of atmospheric carbon dioxide (CO_2) potentially affects the amount of herbivore damage experienced by plants. NSF researchers quantified key aspects of leaf chemistry and the amount of leaf tissue damaged by chewing insects for 12 hardwood tree species grown in large forest plots exposed to elevated CO_2 to simulate atmospheric conditions anticipated by the year 2050. Although there was considerable variation among years, elevated CO_2 decreased herbivore damage in these tree species. This decline may have been related to lower average nitrogen content and a greater content of plant defense chemicals in leaves grown under elevated CO_2. Damage to the leaves of hardwood trees by herbivorous insects may be reduced in the future as the concentration of CO_2 continues to increase. This may alter the feeding behavior of birds and other insect predators in forest ecosystems. **Highlight ID: 11035 BIO/IOS**

Cyberinfrastructure and Biodiversity

Biodiversity informatics, an emerging interdisciplinary and data-rich discipline, increasingly enabled by network communication and computer-based research collaborations, is transforming the way biologists and ecologists approach science. In January 2006, the government science agencies of Mexico, Panama, Costa Rica, and Columbia, and the NSF in the United States joined forces to sponsor a workshop on "Cyberinfrastructure for International Biodiversity Research Collaboration" in Panama City, Panama. The workshop participants, representing a mix of cyberinfrastructure and environmental science specialists, explored science research and education goals, funding priorities, and the technical capabilities needed to advance and sustain regional cyberinfrastructure for biodiversity and ecological research.

Two follow-on activities were implemented as a result of the workshop. The first, a Pan-American Advanced Studies Institute (PASI) on the theme "*Cyberinfrastructure for International, Collaborative*

Biodiversity and Ecological Informatics," took place at the University of Costa Rica and the Organization for Tropical Studies (OTS) La Selva Biological Research Station in late 2007. (PASIs are short training courses/workshops on a current research topic, supported by NSF and the Department of Energy.) The two-week PASI emphasized the development and application of Internet-based cyberinfrastructure tools for environmental research collaboration. The geographical focus for the PASI was the United States, Mexico, Colombia, Costa Rica, and the other countries of Central America.

Second, an NSF Small Grant for Exploratory Research (SGER) award will create a working group of environmental and network researchers from the United States and Latin America. This working group will evaluate networking and software requirements for an environmental sensor network in the rainforest at the OTS La Selva Biological Research Station. The output of this study will feed into a regional, open-source software collaboration for environmental monitoring and sensing.

Together, these activities represent strong, focused steps in collaborative research community-building and student training, with a particular emphasis on cyberinfrastructure and computational methodologies needed to advance regional-scale environmental research. Biodiversity researchers, who have long worked across political boundaries on biological systems, will see their collaborative efforts enabled and transformed using international network communication and services. **Highlight ID: 13683 OD/OISE**

How Climate Change Is Choking Marine Ecosystems

While investigating the effects of climate change on nitrogen cycling in temperate coastal systems, Rhode Island researchers made the first scientific link between warming and fundamental changes in nutrient cycles. Researchers found that the observed estuary shifted from acting as a nitrogen filter to acting as a nitrogen source—which has a profoundly negative impact on marine ecological systems. Previously, when denitrification (removal of nitrogen) dominated the cycle, coastal marine sediments cleansed the water of excess nitrogen. When nitrogen fixation, the process of converting nitrogen into a biologically usable form of nitrogen (such as ammonium or nitrate), dominated the cycle, more nitrogen was brought into the system. Researchers discovered that the sediments added more than 1.5 times the amount of nitrogen from the land and atmosphere combined. If this process is happening in other places, the sediments can produce large amounts of nitrogen, which could have significant consequences for offshore systems. The investigator who led the research is now examining nitrogen cycling in the Louisiana wetlands to determine whether similar conditions exist. **Highlight ID: 16943, OD/OIA**

EcoPod: An Electronic Field Guide for Informed Amateurs and Professionals

EcoPod is a PDA-based mobile capture and access system that enhances the value of observations made by researchers and citizen-scientists—trained volunteers who work on real-world questions—around the globe by increasing both the efficiency of the identification process and its reliability. Biological studies rely heavily on large collections of observations of species. For example, changes in the abundance of certain species or the timing of life events, such as flowering time, are critical to understand the effects of urbanization and climate change or the invasion of foreign animal species on local crops. Professional efforts are limited by geography and time. Thus, expanded access to easy-to-use tools can allow amateurs to make important scientific contributions. Communities of amateurs have yielded key insights, for example, in identifying critical habitat for the Monarch butterfly or changes in bird migration patterns and abundance. The challenge with such contributions is their questionable quality.

Identification is done by decision trees (graphs of decisions with branches showing alternatives), which are called "keys" in biology. EcoPod technology saves time by soliciting as little information from the user as possible to identify a species. This optimization of minimization is accomplished by continuously analyzing the most discriminating questions to ask the user about the specimen at hand and selecting only the characteristics that can be observed in the field at a given time and location; that is, the system has context awareness. At the same time, EcoPod places no restrictions on the order in which its users enter characteristics they observe. The tool records the results of identifications and creates a step-by-step record of the identification process, thereby providing an audit trail for quality assurance. The system also has rapid recovery from mistakes and terminates the process when no additional steps are necessary to make an identification. Users may create and attach written notes and photos to decision points along the way. All of this can be uploaded to large databases, such as eBirds or "Butterflies I've Seen," without additional transcription to Web-forms.

While designed with ecologists and other field researchers in mind, the technology can be generalized to other observation-based decision processes, such as systematics, medicine, design, and other evidence-based professions. **Highlight ID: 12200 CISE/IIS**

Nature Versus Nurture: How Does Genetic Structure Affect Plant Response to Environmental Cues?

Why did daffodils and cherry trees bloom in the middle of January in Washington, D.C., in 2007? Will such unseasonable flowering be common in the future as global warming leads to milder winters? If so, how will this seasonal mismatch affect crop yields or the persistence of wild plant populations? To answer such questions, it is important to understand how plants combine information from multiple environmental cues—such as day length, growth temperature and past winter chilling—to flower in favorable seasonal conditions, and how natural genetic differences in responses to these cues allow plants to inhabit diverse geographic regions and respond to ongoing climate change. An interdisciplinary research team, headed by Johanna Schmitt, is studying natural genetic variation in flowering responses in the tiny weed *Arabidopsis thaliana* (mouse ear cress). This plant—a close relative of crops such as canola, broccoli, and cabbage—is the principal model used in molecular plant genetics research.

Arabidopsis is native to Eurasia and present throughout most of North America. Across the native range, the species inhabits a wide range of climates, from Mediterranean to subarctic. To investigate the genetic mechanisms underlying this broad climatic range, the research team is collecting molecular, genetic, and ecological data for sets of plants derived from the different ecological and environmental settings (ecotypes) of *A. thaliana* across the native geographic ranges. They are testing whether observed DNA variation of the ecotypes is associated with natural geographic differences in flowering responses. At the same time, the team is growing the ecotypes under natural field conditions in different sites in Spain, eastern and western Germany, England, and Finland, in collaboration with seven leading European *Arabidopsis* researchers, to determine how natural genetic variation in the flowering mechanisms affects performance across the climatic range of the species.

Preliminary findings suggest that a natural variant of a single gene can change the entire life cycle of the plant from one that requires winter chilling for flowering and has one generation per year to one that does not require chilling to flower and has several generations per year in regions where the growing season is long and mild. As in the United States, recent winter weather has been unusually warm in Europe, so the team has also had an unexpected opportunity to examine its effects on the flowering and reproductive success of *Arabidopsis* plants under field conditions, taking detailed measurements of the environmental cues the plants experience in each site. Just like the cherry trees in Washington, many of the experimental plants flowered unexpectedly and unseasonably early, which allowed the team to examine the genetic basis of flowering responses to a warming climate.

Understanding how natural genetic differences affect flowering patterns in response to environmental cues is an important step in recognizing the overall interplay of environmental influences on genetics. This groundbreaking research could not only advance the understanding of plant genetics and development, but could potentially lead to advances in crop engineering and other pioneering fields.
Highlight ID: 16938, BIO/EF