6 | Ecosystems

Strategic Research Questions

8.1 What are the most important feedbacks between ecological systems and global change (especially climate), and what are their quantitative relationships?

8.2 What are the potential consequences of global change for ecological systems?

8.3. What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

See Chapter 8 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

Ecosystems supply food, fiber, fuel, clean air and water, and many other goods and services to society. Global change is affecting the provision of these goods and services by altering ecosystems and biodiversity in complex ways. Observational and experimental studies reveal shifting ecosystem boundaries, changes in flowering or migration times, changes in ice breakup on streams and rivers, and changes in productivity and disturbance regimes (e.g., fires, pest and disease outbreaks). These observed changes might be associated with climate variability [e.g., El Niño Southern Oscillation (ENSO)], as well as other global changes such as gradual climate warming and fragmentation of ecosystem habitats.

The role of CCSP-supported ecosystems research is to increase the knowledge necessary to forecast the potential magnitude of global change effects on ecosystems and their feedbacks to the climate system, to help society respond effectively. In

FY 2006, research on ecosystems within CCSP will continue to focus on changes in ecosystems and the frequency and intensity of disturbances to ecosystem processes associated with global change, particularly those anticipated to have significant consequences for society during the next 50 years. This research will enable society to better protect both aquatic and terrestrial ecological resources and their goods and services.

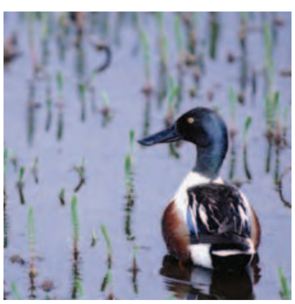
Successful research on the interactions of global change and ecosystems requires collaboration across agencies, as well as ongoing input from scientists within and outside the Federal Government to address scientifically important and socially relevant issues. To meet the goals of the ecosystems research element described in the *CCSP Strategic Plan*, the participating agencies work collaboratively on many research activities. Most of the research accomplishments and plans described in this chapter represent the joint efforts of multiple agencies. To engage the research community in providing input and feedback, the CCSP Ecosystems Interagency Working Group (EIWG) organized a workshop to bring together a broad array of scientists who were asked to identify and articulate priority research topics in support of the *CCSP Strategic Plan* for ecosystems research. Their report will be released in winter 2006 and will be an important reference as CCSP and participating agencies continue to develop science and implementation plans.

The ecosystems component of the FY 2006 CCSP budget request targets several high-priority research needs. One is improved measurements at multiple scales to better quantify and model ecological feedbacks to atmospheric chemistry and climate. Research is also being conducted to develop satellite tools that combine satellite observational data with physical and ecological models. These tools will improve our ability to understand and project changes in the distribution of organisms with changes in climate and other environmental factors. A number of projects on feedbacks between ecological systems and global change are closely related to feedbacks being investigated through other research elements. For example, carbon cycle feedbacks to warming, which are potentially quite significant, are handled largely by the global carbon cycle research element, but with input from the ecosystems research element. Land-surface biophysical feedbacks, which can be quantitatively significant in some modeling schemes, are handled through interactions with the land-use/land-cover change and the climate variability and change research elements. Related research in the ecosystems research element is being coordinated with these groups.

Aquatic ecosystem research priorities in FY 2006 include using integrated modeling systems, observations, and process studies to project the effects of climate variability and change on near-coastal and marine ecosystems, communities, and populations.

Research is also being conducted on the combined effects of changes in land use and climate on nonpoint sources of pollution entering estuaries. Estuaries are chosen because they are the natural integrators of upstream changes in land use and climate. The combined effects of other environmental factors on aquatic ecosystems are also being examined: studies of the effects of ultraviolet (UV) radiation and elevated carbon dioxide (CO_2) on freshwater planktonic lakes, shallow estuarine waters, and deeply mixed clear waters are being conducted using field work, observations, and ecosystem models.

Terrestrial ecosystems research priorities in FY 2006 include a long-term study of the western U.S. mountains and the relationship of observed sudden ecosystem changes to changes in climate conditions (e.g., reduction in the size of glaciers, changes in alpine treelines at their transition zone); the role of recent past, current, and future land-use change on carbon dynamics in eastern deciduous forests; and the effects of climate change on tree species population genetic structure to identify the genetic processes most critical to population survival and how they interact to affect species fitness. Long-term manipulative field experiments will be continued to better understand effects of warming, changes in precipitation, and changes in atmospheric composition on the functioning of forest, grassland, and shrubland ecosystems. A final priority topic is research on the effect of crop rotation, tillage, and nitrogen fertilization on the net global warming potential of agricultural systems, with the purpose of producing methods that may limit global warming potential in irrigated and rain-fed cropping systems while sustaining agricultural yields.



Highlights of Recent Activities

EIWG-Sponsored Workshop on Priority Setting for Ecosystems Research in CCSP. The EIWG sponsored a workshop, held in February 2004 in Silver Spring, Maryland, that brought together a diverse group of 70 scientists from U.S. universities, research centers and institutes, and Federal agency research programs in a "think tank" atmosphere for 3 days. The specific objective was to identify and articulate priorities and approaches for research under Chapter 8 of the *CCSP Strategic Plan*. Although the EIWG organized and funded it, the workshop was run by a steering committee from the science community. The workshop report is due in the winter of 2006 and will be available on the CCSP web site (see <www.usgcrp.gov/usgcrp/Library/ecosystems>).

Convergence in Ecosystem Water Balance over Continental Scales.[9] Water availability limits plant growth and production in almost all terrestrial ecosystems, but biomes differ substantially in sensitivity of aboveground plant growth, or aboveground net primary production (NPP). A recent synthesis building on over 10 years of productivity data from 14 sites in North America showed that rainfall-use efficiency decreased across biomes as mean annual precipitation increased. However, during the driest years at each site, there was convergence to a common maximum value typical of arid ecosystems. In years when water was most limiting, deserts, grasslands, and forests all exhibited the same rate of biomass production per unit rainfall, despite differences in physiognomy and site-level differences in efficiency. Incorporating this information into ecosystem models will improve forecasts of future ecosystem behavior in the face of climate change.

Global Patterns in Human Appropriation of Net Primary Production.[10] Biophysical models were used in conjunction with data from the United Nations Food and Agriculture Organization to estimate the annual amount of Earth's terrestrial NPP or plant growth that humans require for food, fiber, and fuel using the same modeling architecture as satellite-supported NPP measurements. The amount of Earth's NPP required to support human activities is an aggregate measure of human impacts on the biosphere and an indicator of societal vulnerability to climate change. The amount of human-appropriated NPP (HANPP) for each country was calculated on a per capita basis for products consumed and then projected onto a global map of population to create a spatially explicit map of NPP-carbon "demand" (see Figure 20). The HANPP map was compared to a map of "supply" derived from Advanced Very High-Resolution Radiometer data from satellites. It was found that humans consume 20% of Earth's total NPP on land, with regional balances ranging from 6% consumed in South America to over 70% consumed in Europe and Asia, and local balances ranging from near 0% (central Australia) to over 30,000% for major urban areas (e.g., New York City). The uneven distribution of NPP supply and demand indicates the degree to which countries rely on NPP "imports" and suggests options for slowing future growth in NPP demand.

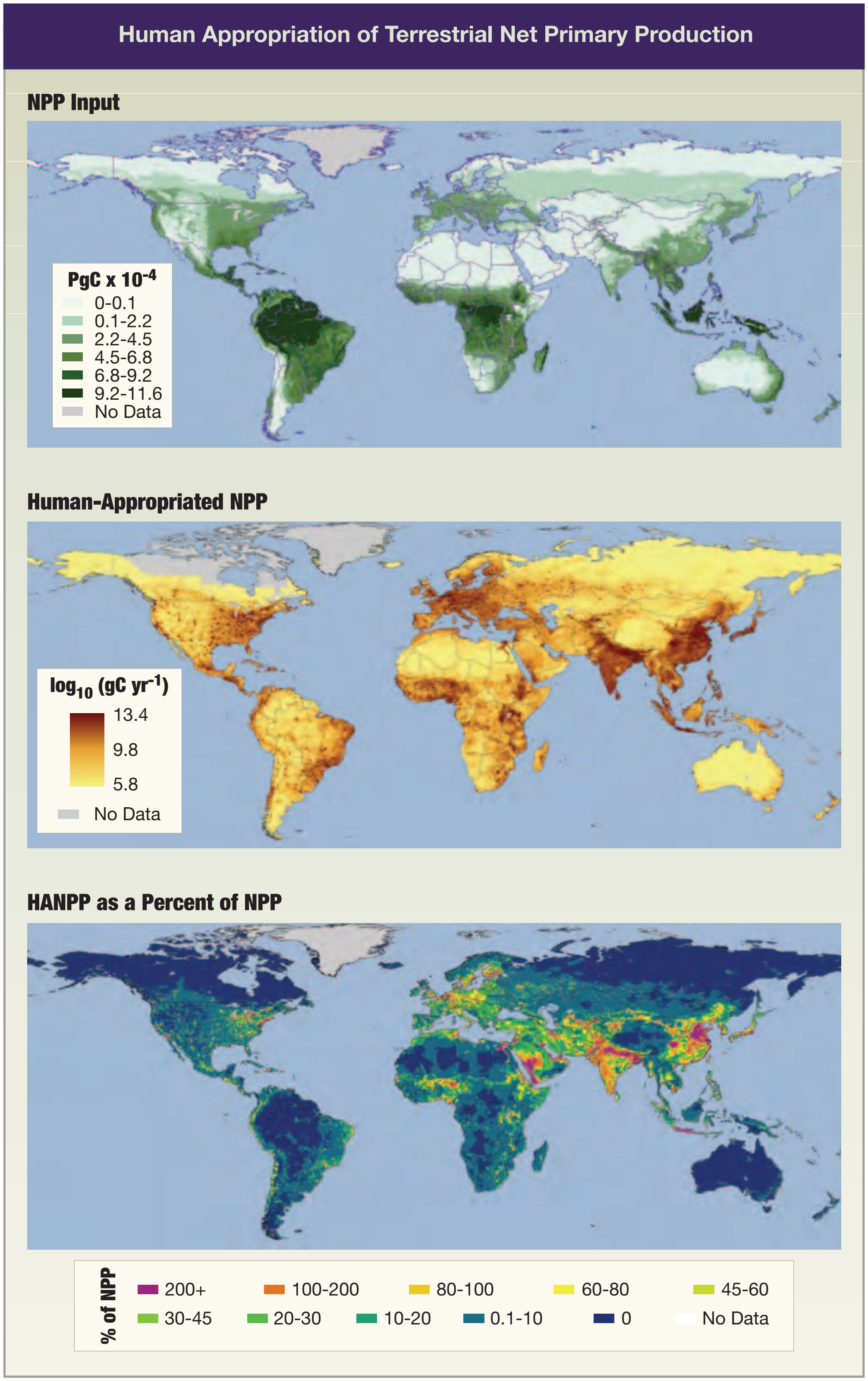


Figure 20: Human Appropriation of Net Primary Production on Land. Average annual terrestrial NPP (i.e., 'supply') based on 17 years of AVHRR satellite data (top); global distribution of human-appropriated NPP (HANPP, i.e., 'demand') for all food and fiber products (middle); and NPP-carbon balance (HANPP as a percent of NPP, calculated for each grid cell) (bottom). Highly populated areas (yellow and red) consume up to 300 times their local production. *Credit: M. Imhoff, NASA/Goddard Space Flight Center*.

Ocean Photosynthesis from Space.[1] The rate of photosynthesis for a given area is determined by its biomass of living plant material, the plants' growth rates, and the availability of sunlight. Until now, quantifying photosynthetic rates over large ocean areas has been difficult, if not impossible, because growth rates could not be characterized from space. The path to solving this problem is to use ocean color data analysis – specifically the application of partial wave analysis – that permits estimates of both the carbon biomass of ocean plants and their growth rates. This development will make it possible to use satellite remote sensing to improve estimates of ocean photosynthesis and detect changes over time.

Warming Interactions with Soil Carbon and Nitrogen in the Arctic Tundra.[12] Research results from the Arctic tundra in Alaska demonstrated how warming and consequent release of nutrients from increasingly decomposing soil organic matter will feed back positively and lead to increasing carbon losses from tundra soils. Data from a 20-year fertilization experiment showed that increased nutrient availability caused a net ecosystem loss of almost 2,000 gC m^{-2} (a 21% reduction over the 20-year period), even though annual aboveground plant production doubled, because of losses of carbon and nitrogen from deep soil layers. The results suggest that projected releases of soil nutrients associated with high-latitude warming may further amplify carbon release from soils, causing a net loss of ecosystem carbon and a positive feedback to climate warming.

Effects of Nitrogen Deposition on Water Quality and Carbon Sequestration.[16] Human effects on the natural cycling of nitrogen have caused significant alterations of land productivity, freshwater quality, and marine ecosystems. Nitrogen compounds generated by human activities are transported by the atmosphere and deposited onto ecosystems. Healthy forests remove much of the deposited nitrogen, storing it in plant tissues. In the Chesapeake Bay watershed, for example, forests retain 88% of deposited nitrogen, allowing only about 1 kg ha^{-1} yr^{-1} to leach into aquatic ecosystems (see Figure 21). As the level of deposition rises, the percentage of nitrogen retained declines and the amount of nitrogen released into downstream ecosystems increases. Nitrogen deposition will increase productivity in terrestrial ecosystems that are nitrogen deficient. Net carbon uptake by forests of the mid-Atlantic region could increase by 25% from nitrogen deposition; however, this rate of increase may be reduced by ground-level ozone pollution, which is damaging to many plant species.

Ecosystem Warming Facility Constructed and Operational. An ecosystem warming experimental facility was constructed in a boreal forest in northern Manitoba, Canada, and began operation during FY 2004. The facility exposes trees and soils to temperatures 5°C above ambient to examine potential effects of warming

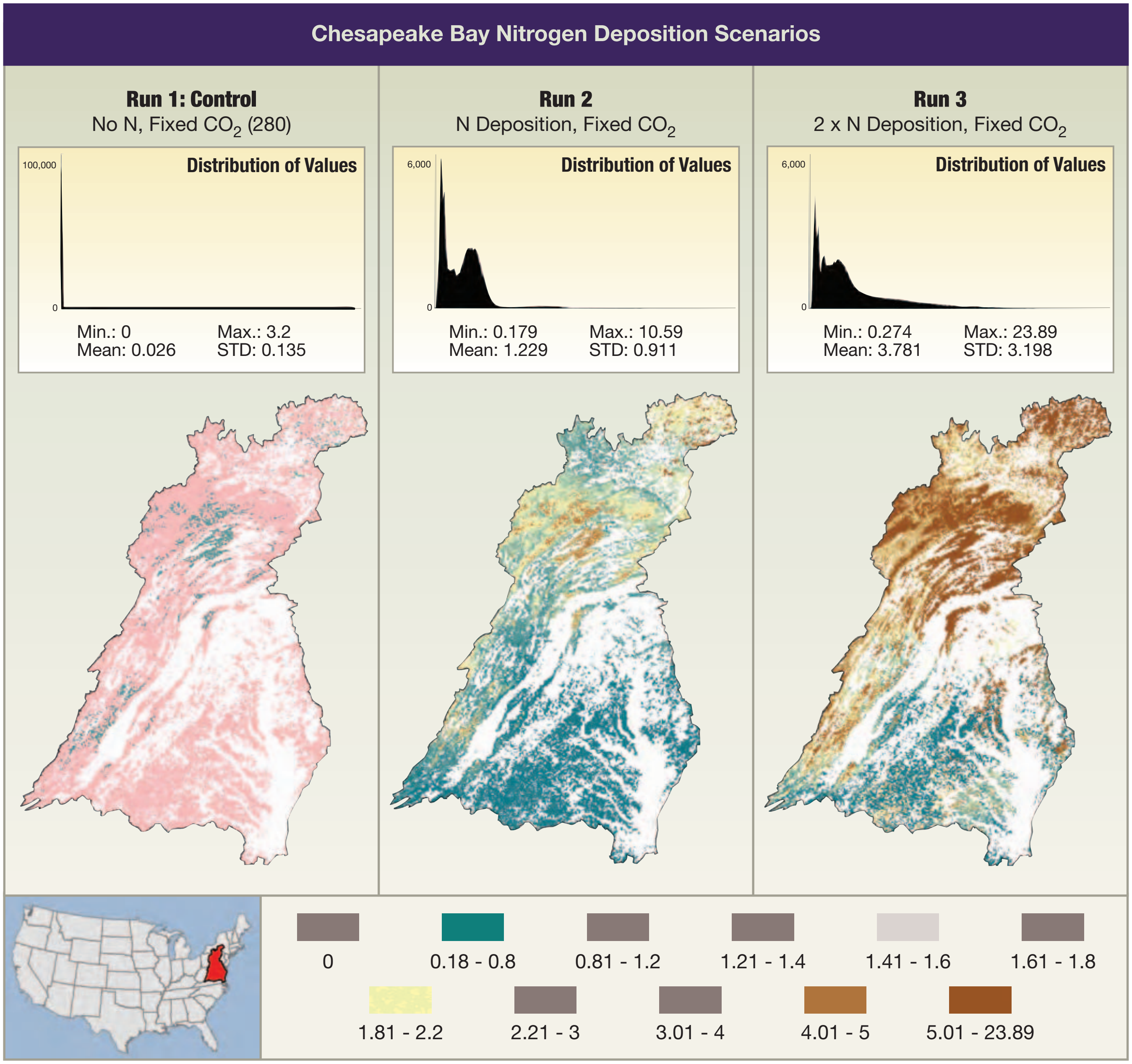


Figure 21: Chesapeake Bay Nitrogen Deposition Scenarios. Predicted losses of nitrogen from forested lands of the Chesapeake Bay watershed under no nitrogen deposition (left), current nitrogen deposition (middle), and doubled nitrogen deposition (right).
Credit: Pan et al.*, 2004*.

on northern forests. Preliminary (FY 2004) data show acclimation of soil respiration to warming such that the rate of respiration (CO_2 release) following warming was about the same as the rate prior to warming, indicating a nearly complete acclimation to warming in the belowground component of the ecosystem. This result, if corroborated by continued data collection in FY 2005 and beyond, has important implications for understanding a potential positive feedback on global warming caused by increased soil respiration in northern ecosystems (i.e., such a positive feedback might not occur in all ecosystems). In the warmed plots, tree growth began earlier in the spring and the growth of understory plants was greatly increased. Such changes in plant growth and its seasonal timing are important to the energy balance of northern ecosystems as the climate warms, and could result in a positive feedback to warming. Early results indicate greater carbon gains in the warmed plots relative to the ambient plots. For more information on this facility, see <per.ornl.gov/>.

Elevated Carbon Dioxide Effects on a Florida Ecosystem.[8] A study of a Florida scrub oak forest ecosystem suggested for the first time that the abundance of a trace element influenced the response of vegetation to elevated CO_2. The response of a nitrogen-fixing plant to elevated CO_2 declined over a 7-year period. The decline was strongly correlated to a decline in molybdenum, an element required for producing a key enzyme that affects nitrogen uptake by plants. The work illustrates that plant responses to elevated CO_2 may be highly species-specific. It also raises the possibility that the expected increase in plant growth due to elevated CO_2 could be limited by the availability of nitrogen.

Effects of Climate Change on Eastern U.S. Bird Species.[14] An atlas was produced that documents the current and potential future distribution of 150 common bird species in the eastern United States in relation to climate and vegetation distributions. Distribution data for individual species were derived from the Breeding Bird Survey from 1981 to 1990. Models were developed that related distributions of individual bird species to environmental variables (tree species abundance, climate variables, and elevation variables). Two scenarios of global climate change were then used to project potential changes in the distributions of the bird species. Depending on the global climate model used, as many as 78 bird species are projected to decrease by at least 25%, while as many as 33 species are projected to increase in abundance by at least 25% due to climate and habitat changes (see Figure 22 for an example).

Climatic Variability, Ecosystem Dynamics, and Disturbance in Mountain Protected Areas.[2,3,4,5,7,17,18] Northwestern mountain ecosystems play an important role in shaping the economies and landscape development of the region and provide services such as water purification and storage, and recreational opportunities. A project was initiated to quantify how the hydrological and ecological aspects of these ecosystems respond to climatic variability and large-scale landscape disturbance by examining past responses and projecting possible future outcomes of ongoing climatic change. The research project, Climate-Landscape Interactions on a Mountain Ecosystem Transect (CLIMET), was carried out across a transect of mountain systems

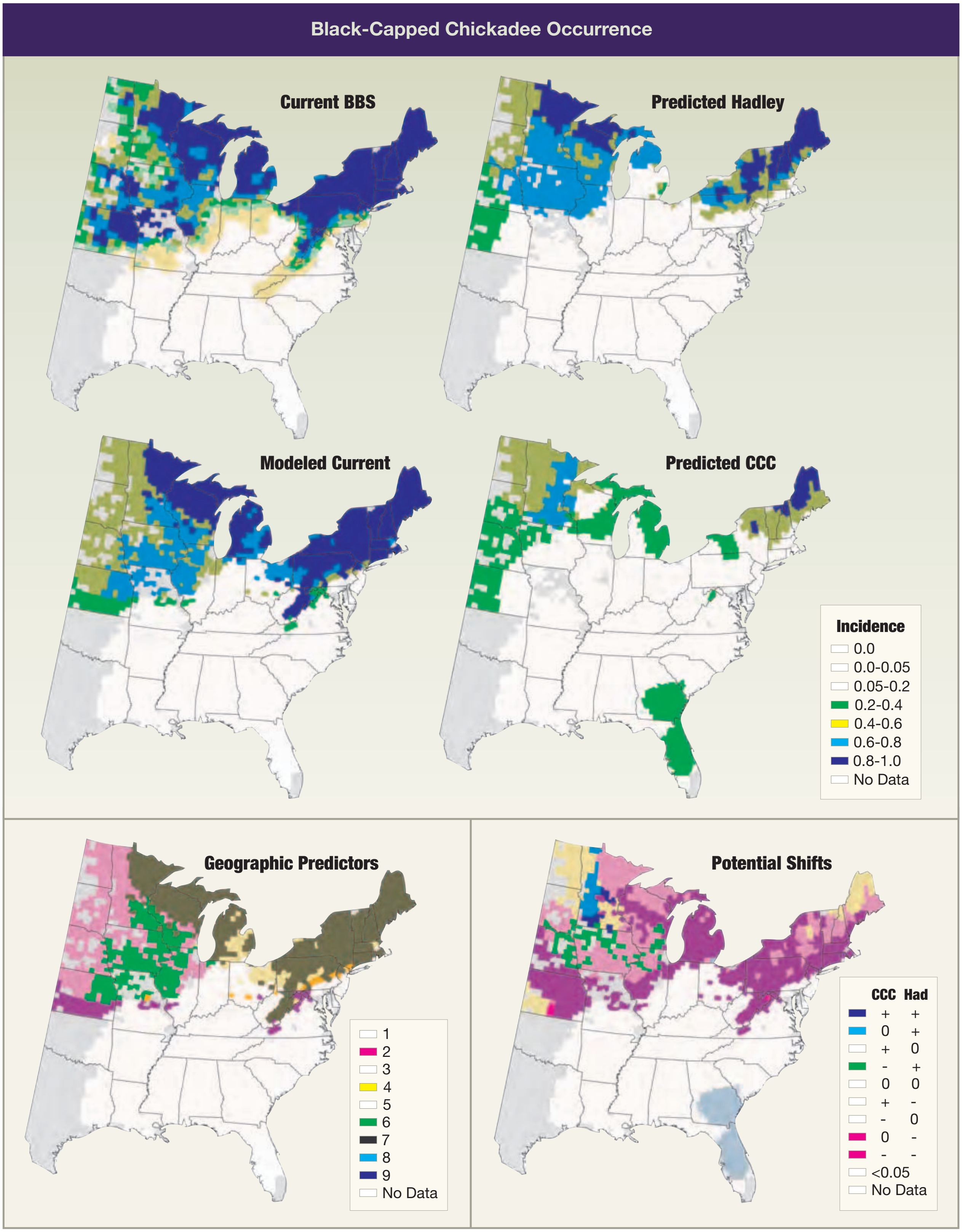


Figure 22: Black-Capped Chickadee Occurrence. Potential changes in occurrence of the Black-Capped Chickadee under two climate scenarios. “Incidence” refers to the proportion of sightings during annual breeding bird surveys. *Credit: Matthews* et al.*, 2004*.

along gradients of maritime to continental climate and decreasing landscape fragmentation (Olympic National Park, North Cascades National Park, and Glacier National Park) (Fagre and Peterson, 2002). The project has provided information on glacial decline, alpine forest changes, and ecological responses to climate variability (Fagre *et al.*, 2003). For example, an analysis of digital aerial photography and historical data documents that the number of glaciers in Glacier National Park has dropped from an estimated 150 in 1850 to 27 present today. The largest glaciers are, on average, only 28% of their previous size (see Figure 23). Future glacial recessions and vegetation distributions were projected using a geospatial modeling approach. Projections indicate that the largest glaciers will be gone in the northern Rocky Mountains by the year 2030 if current rates of warming continue (Hall and Fagre, 2003). The loss of glaciers in mountain watersheds will change the timing and amount of stream discharge and affect aquatic organisms dependent on cold waters.

Data are becoming available on the response of mountain ecosystems to climatic variability, particularly to multi-decadal trends in moisture. One such long-term pattern is the Pacific Decadal Oscillation (PDO), a period of above- or below-average sea surface temperatures in the Pacific Ocean that influences climate in the northwest part of North America. Mountain snowpacks in Glacier National Park track the PDO very closely and show regular 20- to 30-year periods of greater and lesser snow cover (Selkowitz *et al.*, 2002). These patterns explain glacier fluctuations and periods of increased tree growth in the northern Rocky Mountains (Pederson *et al.*, 2004). The frequency and size of forest fires in the Pacific Northwest also show a clear response to the PDO (Hessl *et al.*, 2003). Analysis of tree ring widths from drought-sensitive trees indicates that such multi-decadal oscillations have had an influence on these mountain environments for the past 500 years or more (Gedalof *et al.*, 2005). Such results suggest that it may be possible to forecast general mountain ecosystem responses to continuing climatic oscillations.

Sensitivity of Forests in Northern California to Climate and Fire Regime Variation.[19,21] Often, fire appears to serve as a catalyst for change during periods of rapid climate change. Time-series analyses show that vegetation associations with large, long-lived species (conifers) appear to lag in response to climate variations until major fires (as seen in charcoal influx to sediments) reset the stage and encourage major vegetation reorganization. This provides evidence of the potential influence of catastrophic fire on the reorganization of ecosystems under periods of rapid climate variation and could have major implications for habitat and forestry.

Leaf Pores: An Important Link among Increasing Greenhouse Gases, the Water Cycle, and Rising Temperatures.[13,15] Carbon dioxide and ozone (O_3), both greenhouse gases, directly affect plant physiological processes, including photosynthesis.

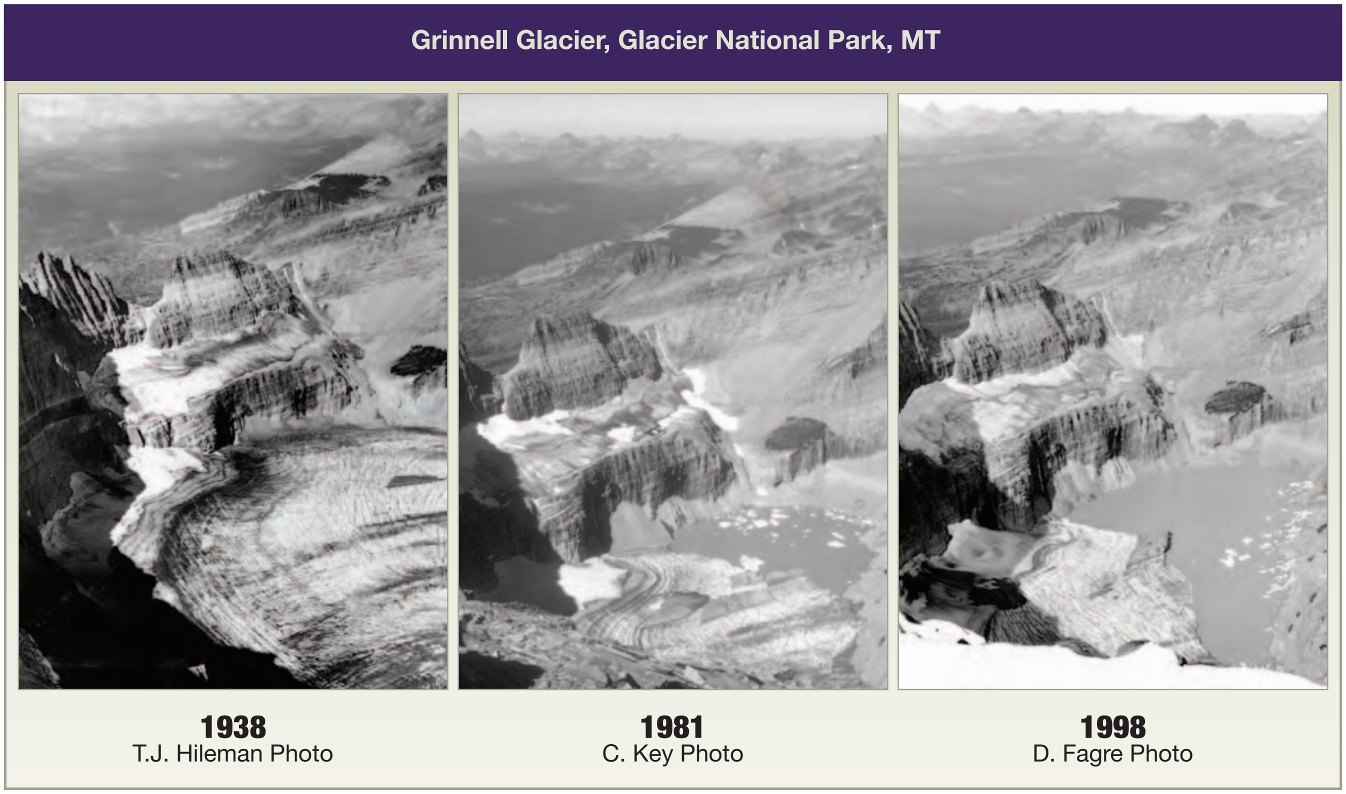


Figure 23: Glacier Retreat over the Past Century. Repeating photographs from the same location have provided visual documentation of the extent of glacier retreat over the past century. *Credit: USGS/Northern Rocky Mountain Science Center*.

These gases affect the opening and closing of microscopic pores (stomata) on plant leaves that regulate movement of water from the soil, through the plant, and into the atmosphere. Water vapor escaping through these pores cools the leaves and is important in the global water cycle. The number of stomata per unit of leaf area in grassland plant species in the southern United States was measured after the plants had been exposed for 4 years to a continuous CO_2 gradient spanning pre-industrial to near-double ambient concentrations. At higher CO_2 levels, stomatal density was greater for two species, decreased for one species, and unchanged for four species. In another field experiment using FACE technology, soybean plants were grown in the field at CO_2 and O_3 concentrations projected for the mid-21^{st} century to explore how these changes in atmospheric composition might affect a nationally important agroecosystem. This work has provided the first field-scale evidence that rising CO_2 and O_3 concentrations decrease the loss of water vapor through the stomata and have the potential to substantially reduce summer moisture supply to the atmosphere (at the same time conserving soil moisture) and cause a warming of vegetated surfaces that will raise surface temperatures independently of greenhouse warming.

U.S. Marine Resource Managers Seek Guidance from Climate Scientists on Impacts of Regime Shifts.[11] Mounting evidence indicates that decadal climate changes in ocean productivity must be considered in assessments of fish stocks. In 1998, marine resource managers perceived a climate regime shift in the North Pacific. This shift resulted in cooler ocean conditions within the California Current System and Gulf of Alaska, but warmer surface waters in the central North Pacific. These changes apparently led to increased biological productivity within much of the California Current System and Gulf of Alaska (e.g., increased abundance of plankton and recruitment of many commercial fish stocks including Pacific salmon species, Pacific hake, and groundfish in the California Current System, and Pacific salmon species, shrimp, pollock, Pacific cod, and sablefish in the Gulf of Alaska), but decreased productivity in the Central North Pacific (e.g., northward shift in the low chlorophyll surface waters and decreased survival of monk seal pups in the northern atolls of the northwestern Hawaiian Islands). In response to this, the U.S. National Marine Fisheries Service requested advice from the North Pacific Marine Science Association on the potential effects of climate change on fish stocks in the North Pacific. An ad hoc group of U.S. and international scientists was formed, confirmed that the North Pacific entered a new climate state in 1998, and detailed the associated changes. The group advised agencies to develop management policies with explicit decision rules and subsequent actions to be taken when there are preliminary indications that a regime shift has occurred. Existing indicators, such as temperature and primary production, make it possible to detect shifts soon after they occur, but due to limited understanding of the mechanisms that lead to regime shifts, it is not possible to reliably predict how long any new state will last. The report included four recommendations for incorporating regime shift concepts into fishery management activities: accept the regime concept for marine ecosystems; develop and maintain a comprehensive observational program to monitor changes; develop climate indices to aid ecosystem monitoring efforts; and make use of fish stock assessments to evaluate the vulnerability of ecosystems to various future regime scenarios.

New Long-Term Ecological Research Network Sites in Coastal Areas. The addition of the Moorea Coral Reef and the California Current Ecosystem to the Long-Term Ecological Research (LTER) Network has expanded the number of LTER sites to 26. These two new sites significantly augment the LTER Network, which had previously included only one marine site in the Antarctic, and ensure that high biodiversity and productivity ecosystems in most of the world's major biomes are represented in the network. Understanding gained from the site on the island of Moorea in the South Pacific will enable more accurate projections of how coral reef ecosystems respond to environmental change, whether human-induced or from natural cycles. The California Current System sustains active fisheries for a variety of finfish and shellfish, modulates

weather patterns and the hydrologic cycle of much of the western United States, and plays a vital role in the economy of myriad coastal communities. Research will focus on how the influences of El Niño, the PDO, and multi-decadal warming trends affect these systems. The LTER program continues to have a major network-wide focus on climate change impacts on ecosystems (see <www.lternet.edu>).

Coral Reef Watch: Satellite Input.[6,20] The number of reported coral reef bleaching events was minimal before the ENSO events of 1998 and 2002. During these events, significant coral mortality occurred throughout western Pacific and Caribbean coral reefs, bringing to light one likely correlation between anomalous temperatures and ecosystem response (Urban *et al.*, 2000). Since then, scientists have been developing an understanding of the potential causes and links leading to significant coral bleaching events. The Coral Reef Watch Program (see <coralreefwatch.noaa.gov>) uses land- and satellite-based instruments and *in situ* tools for near-real-time and long-term monitoring, modeling, and reporting of physical environmental conditions of coral reef ecosystems. Biological, physical, and environmental data critical to coral reef ecosystems are continuously received, input into Coral Reef Watch, and provided to Reefbase (see <www.reefbase.org>), a global information system. These data are used to help design future marine protected areas, coral reef parks and refuges, and research areas (Heron and Skirving, 2004). Linking ecosystem models with current and past climate data will enable scientists to understand the relationship between climate parameters and coral ecosystem response. These efforts will provide tools that managers and stakeholders can use in the field to conserve corals. It is important to continue the acquisition of Landsat-like satellite data for these purposes.

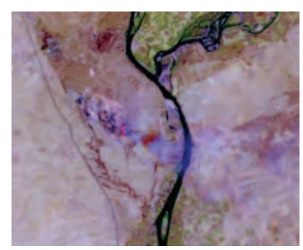
Creation of the National Ecological Observatory Network. Work was initiated with the American Institute for Biological Sciences to set up a National Ecological Observatory Network (NEON) Design Consortium and Project Office. This consortium will develop a blueprint for the network and a plan for its implementation. NEON will be the first national observation system designed to answer ecological questions at regional and continental scales. Data from the network will help to develop a predictive understanding of the relationship between environmental change and biological processes. Focus areas for NEON include the impact of climate change on forests and agriculture, the emergence and spread of infectious diseases, the causes and consequences of invasive species, and the forecasting of biological change. For more information, see <www.neoninc.org>.

Highlights of FY 2006 Plans

Definition of Requirements for Ecosystem Observations. An ongoing analysis of existing data, model projections, and conceptual hypotheses is expected to be completed during FY 2006. The analysis will draw on output from workshops, reviews of existing scientific literature, and new model calculations to provide an initial definition of the requirements for ecosystem observations needed to quantify ecological feedbacks to climate and atmospheric composition. The specification of requirements will seek to enhance the use of existing observing systems, but will also consider needs for new observing capabilities. The activities to be completed during FY 2006 will focus on the western United States, but are expected to provide a solid scientific base for similar activities for other regions.

These activities will address Question 8.1 of the CCSP Strategic Plan.

Use of Remote Sensing to Detect and Forecast Global Change Effects. By combining satellite observation data with physical and ecological models, progress is being made toward the goal of using remote sensing to relate changes in climate and other environmental factors to changes in the distributions of organisms and how they relate to their environments. The groundwork is being laid for improved satellite-based tools for detection of changes in marine and terrestrial plant physiology as well as for distinguishing between groups of organisms having different roles in the cycling of elements and water. Improvements in our ability to remotely sense the three-dimensional structure of habitats also help to meet the goal. Coupling observationally driven models across spatial scales and model types (e.g., linking regional climate models to ecosystems food web models) is providing a better understanding of the connections between the geophysical and biological components of this planet. In one example planned for FY 2006, integrating global climate models and regional climate models with food web models will result in forecasts of the impacts of interannual climate phenomena, such as ENSO events, on the productivity of specific fisheries. These forecasts should promote more sustainable harvests of fish stocks.



These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Models and Indices for Improved Fisheries Management. The ongoing North Pacific Climate Regimes and Ecosystem Productivity project will integrate observations and understanding into predictive models, metrics, and indices of ecosystem status and trends for use in marine fisheries management. Expanded monitoring will increase our understanding of how climate influences the structure and function of ecosystems in the eastern Bering Sea and northern Gulf of Alaska. Central components of the monitoring system are regional biophysical moorings and research cruises. Analyses of data from the monitoring system will be used to construct and validate new conceptual and predictive models and to provide indices of ecosystem status. These results will provide resource managers with knowledge and tools to adapt to the consequences of climate change for marine ecosystems.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Determining the Effects of Climate Variability on Marine Populations. U.S. GLOBEC (Global Ocean Ecosystems Dynamics) is a research program organized to address the question of how global climate change may affect the abundance and production of animals in the sea. It has supported major field research efforts in the Georges Bank/Northwest Atlantic Region, the Northeast Pacific, and the Southern Ocean and western Antarctic Peninsula. These field studies have incorporated observations of physical and biological oceanographic parameters in the three regions, process studies to understand mechanisms and dynamics driving these ocean ecosystems, and modeling developments to link physical and ecological processes in a predictive framework. In FY 2006, researchers will begin synthesizing results to provide increased overall understanding of the responses of these ecosystems to climate variability, and allow predictions of population responses. The U.S. GLOBEC program will also provide advice to guide ecosystem-based management of marine resources in the face of climate change.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Elevation Maps Depicting Areas Vulnerable to Sea-Level Rise and Planning Maps Depicting How State and Local Governments Plan to Respond to Sea-Level Rise. A tool using sea-level rise elevation and planning maps is being designed for coastal planners at all levels for use in developing master plans. It will provide high-precision maps that will delineate low-lying lands that would be eroded or inundated as the sea rises. Along with overlying maps of planned or existing infrastructure, habitat types, and models of ecosystem response to inundation, this will provide managers of coastal development with sufficiently detailed information to accommodate expected consequences of sea-level rise. The ongoing effort will provide this product for part of the coast of North Carolina and be a template for future work along other low-lying coasts.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Effects of Ultraviolet Radiation and Elevated Carbon Dioxide on Aquatic Ecosystems. Ongoing research is being conducted on UV radiation effects in a variety of aquatic ecosystems including freshwater planktonic lakes, shallow estuarine waters of the Chesapeake Bay, and deeply mixed, clear waters of the Ross Sea, all of which can be exposed to enhanced UV-B radiation. The responses of key flux processes (e.g., carbon and nitrogen cycling) to UV radiation are being measured and used to develop ecosystem models that include UV as a factor. The models also include the effects of elevated CO_2 on the production of UV-absorbing carbon compounds in adjacent marsh ecosystems, which are the subject of an ongoing field manipulation.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Linkages between Tropical Storms, Ecosystem Diversity, and Climate Change in Pacific Islands. A research project will examine the effects of a particularly severe typhoon (Sudal) on upland forests, mangroves, and seagrass ecosystems in Micronesia. This typhoon resulted in the deposition of large quantities of wood (fuels) on the forest floor and increased susceptibility to severe wildfire. Shifts in invertebrates of seagrass and mangrove ecosystems, forest structure, and the composition and recovery of the marine and mangrove biota will be measured and compared to similar ecosystems unaffected by recent typhoons on neighboring islands. Observations will continue through 2006. The results will improve information for planning adaptation measures for Pacific Island forest and marine ecosystems and societies to the potential for more severe or frequent tropical cyclones or increases in the occurrence of El Niño events.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Understanding Ongoing Changes in the Mountains of the Western United States. A study was launched by the USGS Fort Collins Science Center, Northern Rocky Mountain Science Center, Western Ecological Science Center, and the USDA Forest Service Pacific Northwest Research Station to better understand ongoing changes in the mountains of the western United States. Aims of the study include understanding the causes of sudden changes in mountainous areas, such as the recent die-off of trees on millions of acres in New Mexico, Arizona, and southern California. Since 2002 in the Jemez Mountains, mortality of overstory piñon has exceeded 95% (by spring 2004), and most piñon seedlings have died. Local piñon-juniper woodlands are being rapidly and massively transformed in the southwestern United States by the current combination of warm and dry climate conditions. These results highlight the potential for rapid, drought-induced changes in woody vegetation due to extreme climate events.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Final Data Collection from the Longest Large-Scale Ecological Climate Change Experiment. The Throughfall Displacement Experiment located in a deciduous hardwood forest in eastern Tennessee has been studying whole-forest responses to altered precipitation, a possible component of climatic change, continuously since 1993. The project has provided much new and unique data during its lifetime, some of which was summarized in a 2003 book devoted to the experiment. This experiment has also served as an important source of data for the development and testing of a wide range of ecosystem models. During FY 2006, final data collection will occur for this large-scale field experiment. The precipitation manipulations will be ended and extensive characterization of the effects of 13 years of chronic changes in the precipitation inputs to the forest ecosystem will be completed.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Polar Bear Survival in a Vanishing Sea-Ice Environment. The polar bear (*Ursus maritimus*) is the top predator of the Arctic marine ecosystem. Throughout their range, they are dependent on sea ice for nearly all aspects of their life history. Evidence indicates that Arctic regions have warmed recently, and that one of the most prominent effects of these changes is an altered sea-ice environment. Hence, polar bears, which may be the first large mammal to show obvious effects of climate change, are an ideal "indicator" of the status of the Arctic system. This study will examine how sea-ice quality and condition have changed and will change for the period between 1985 and 2008. It will establish how polar bears adapt to those changes

spatially, and will test whether there is evidence that spatial responses, mediated by climate change, alter polar bear condition, productivity, and survival of young.

These activities will address Question 8.2 of the CCSP Strategic Plan.

Dynamics of Historic Species Ranges and Implications for Conservation. The effects of climate change on tree species population genetic structure are being quantified. The research approach is primarily through natural experiments; for example, species whose ranges were fragmented by past environmental change, largely the global warming that ended the last glacial period and the Holocene climatic fluctuations that followed. Measures of population structure and health, including genetic diversity, rates of gene flow, and inbreeding, are estimated from molecular markers for threatened and fragmented populations. The goals of the research are to identify the genetic processes most critical to population survival and how they interact to affect species fitness. The findings will be used to recommend management strategies to help provide species and gene conservation. Data collection and analysis will continue in FY 2006.

These activities will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Effects of Changes in Land Use and Climate on Non-Point Source Pollution in Estuaries. Climate and land-use change will affect the constituents of non-point source pollution entering water bodies. Non-point sources of pollution come from agriculture, suburban, and urban land uses. Changes in precipitation, for example, combined with changes in these land uses, will affect the ratio of nutrients and pollutants entering water bodies. Estuaries are natural integrators of upstream changes in land use and climate and are therefore the focus of research to be initiated in FY 2006. Selected locations with water quality monitoring and land-use data will be used to model the effects of climate and land-use changes on ecological endpoints. Best management practices scenarios and the relevant ecological endpoints will be identified through stakeholder workshops. Based on workshop results, analyses will explore management options to estimate their effectiveness at reducing projected impacts on water quality and valued ecological endpoints.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Climate Change Effects on Bioindicators and Biocriteria Programs. Biocriteria are narrative descriptions or numerical values (e.g., community composition, abundance of specific "indicator" species) that are used to describe the condition of a water body that supports aquatic life. Biocriteria help to identify cumulative effects of all stressors within a water body. These ecological indicators may be vulnerable to changes in temperature, stream flow, sedimentation, the timing, amount, and seasonality of precipitation, and land-use changes. Biocriteria programs are designed to compare reference sites with non-reference sites to detect impairment. However, the combination of climate change and land-use change effects on biocriteria may cause baseline conditions at reference and non-reference sites to change, making impairment difficult to interpret. In FY 2006, case studies will be initiated in several States and for several aquatic ecosystems to identify those biocriteria metrics that are sensitive to climate and land-use changes, and those bioindicators that may be used to monitor shifting baselines between reference and non-reference sites. These studies will outline the general implications of climate change and land-use change for aquatic ecosystem health and for biocriteria programs.

These activities will address Question 8.3 of the CCSP Strategic Plan.

Effect of Agricultural Practices on Net Global Warming Potential. Research will provide new information about the effect of crop rotations, tillage, and nitrogen fertilization on the net global warming potential of agricultural systems – that is, the difference between total greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide) and carbon sequestration. Collection of emissions and sequestration data along with soil environmental factors related to trace gas exchange will assist in verification of simulation models that can be used to estimate net global warming potential on larger spatial and temporal scales. In FY 2006, these analyses will lead to the development of methods by which global warming potential can be limited in irrigated and rain-fed cropping systems while sustaining agricultural yields.

These activities will address Question 8.3 of the CCSP Strategic Plan.

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