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?

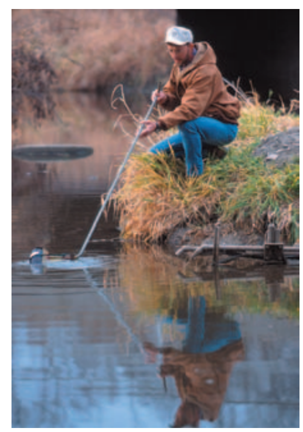
8.3. What are the options for sustaining and improving ecological systems and related goods and services, given projected global changes?

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

Ecosystems shape societies and nations by providing essential renewable resources and other benefits. They sustain human life by providing the goods and services on which life depends, including food, fiber, shelter, energy, biodiversity, clean air and water, recycling of elements, and cultural, spiritual, and aesthetic returns. Ecosystems also affect the climate system by exchanging large amounts of energy, momentum, and greenhouse gases with the atmosphere. The goal of the Ecosystems research element of the Climate Change Science Program is to understand and be able to project the potential effects of global change on ecosystems, the goods and services ecosystems provide, and ecosystem links to the climate system.

Climate variability and change can alter the structure and functioning of ecosystems. This, in turn, can affect the availability of ecological resources and benefits, can change the magnitude of some feedbacks between ecosystems and the climate system, and can affect economic systems that depend on ecosystems. Research during the last decade focused on the vulnerability of ecosystems to global change and contributed to assessments of the potential effects of global change on ecological systems at multiple scales.

We now know that the effects of environmental changes and variability may be manifested in complex, indirect, and conflicting ways. For example, warming may enhance tree growth by extending growing season length (in temperate and cool regions), but pathogens better able to survive the winter because of higher temperature may decrease forest productivity and increase vulnerability of forests to disturbances such as fire. Subtle changes in winds over the ocean can affect currents, which in turn may alter the ranges and population sizes of fish species and increase or decrease fish catches. Whether environmental changes result from human activities or are natural in origin, human societies face substantial challenges in ensuring that ecosystems sustain the goods and services on which we depend for our quality of life and survival itself.



Research should be focused on building the scientific foundation needed for an enhanced capability to forecast effects of multiple environmental changes (such as concurrent changes in climate, atmospheric composition, land use, pollution, invasive species, and resource management practices) on ecosystems, and for developing products for decision support in managing ecosystems. Near-term priorities will be placed on economically important ecosystems and special studies relevant to regions where abrupt environmental changes or threshold responses by ecosystems may occur. Investigations will emphasize changes in ecosystem structure and functioning and changes in the frequency and intensity of disturbance processes anticipated to have significant consequences for society during the next 50 years, including altered productivity, changes in biodiversity and species invasions (including pests and pathogens), and changes in carbon, nitrogen, and water cycles.

Ensuring the desired provision of ecosystem goods and services will require understanding of interactions among basic ecosystem processes and developing approaches to reduce the vulnerabilities to, or take advantage of opportunities that arise because of, global and climatic changes. Scientific research can contribute to this societal goal by addressing three questions that focus on linkages and feedbacks between ecosystems and drivers of global change, important consequences of global change for ecological systems, and societal options for sustaining and enhancing ecosystem goods and services as environmental conditions change. This research will produce critical knowledge and provide a forecasting capability that will continuously improve decisionmaking for resource management and policy development.

Highlights of Recent Research

Highlights of recent research supported by CCSP participating agencies follow.

Ocean primary production decreased since the early 1980s. Satellite and *in situ* chlorophyll records show that global ocean primary production has declined more than 6% since the early 1980s (see Figure 22). Almost 70% of this decline occurred in the high latitudes. The North Atlantic and North Pacific Oceans experienced increases in sea surface temperature of 0.7 and 0.4°C, respectively, over the time period of the study. However, decreases in primary production in the Antarctic basin were not associated with significant warming. Satellite data were blended with *in situ* data and used as inputs to a model that computed seasonal ocean primary productivity. The reduction in primary production may represent a reduced sink of carbon via the photosynthetic pathway in the high-latitude oceans. It is not clear whether the changes observed are part of a long-term trend or if they might be related to decadal-scale climate variations, such as the Pacific Decadal Variability or North Atlantic Oscillation/Northern Annular Mode.

Climate regime shifts in marine ecosystems. Climate regime shifts on multi-decadal time scales affect the productivity of marine and terrestrial systems, thus it is critical to be able to recognize and predict regime shifts to manage ecosystems. Research has produced a new understanding of the impact of regime shifts on ecosystem productivity and structure. In the North Pacific Ocean, the Pacific Decadal Variability changed from warm to cool phase in 1998, and was accompanied by immediate increases in plankton productivity and species composition, and significant increases in numbers of Pacific Northwest salmon and other commercially important fishes. In the North Atlantic Ocean, changes in quantities of zooplankton and fishes were observed, particularly in the Gulf of Maine, associated with a reversal in the North Atlantic Oscillation/Northern Annular Mode. Based on these new findings, indicators of ecological change are being developed for fisheries management and policymakers.

Observed impacts of climate change on plant and animal species. Analyses based on a large number of studies of plants and animals across a wide range of natural systems worldwide have found that many species have shifted their geographic ranges or changed temperature-sensitive behaviors—such as migration, flowering, or egg-laying—in ways consistent with reacting to global warming. However, causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends, over

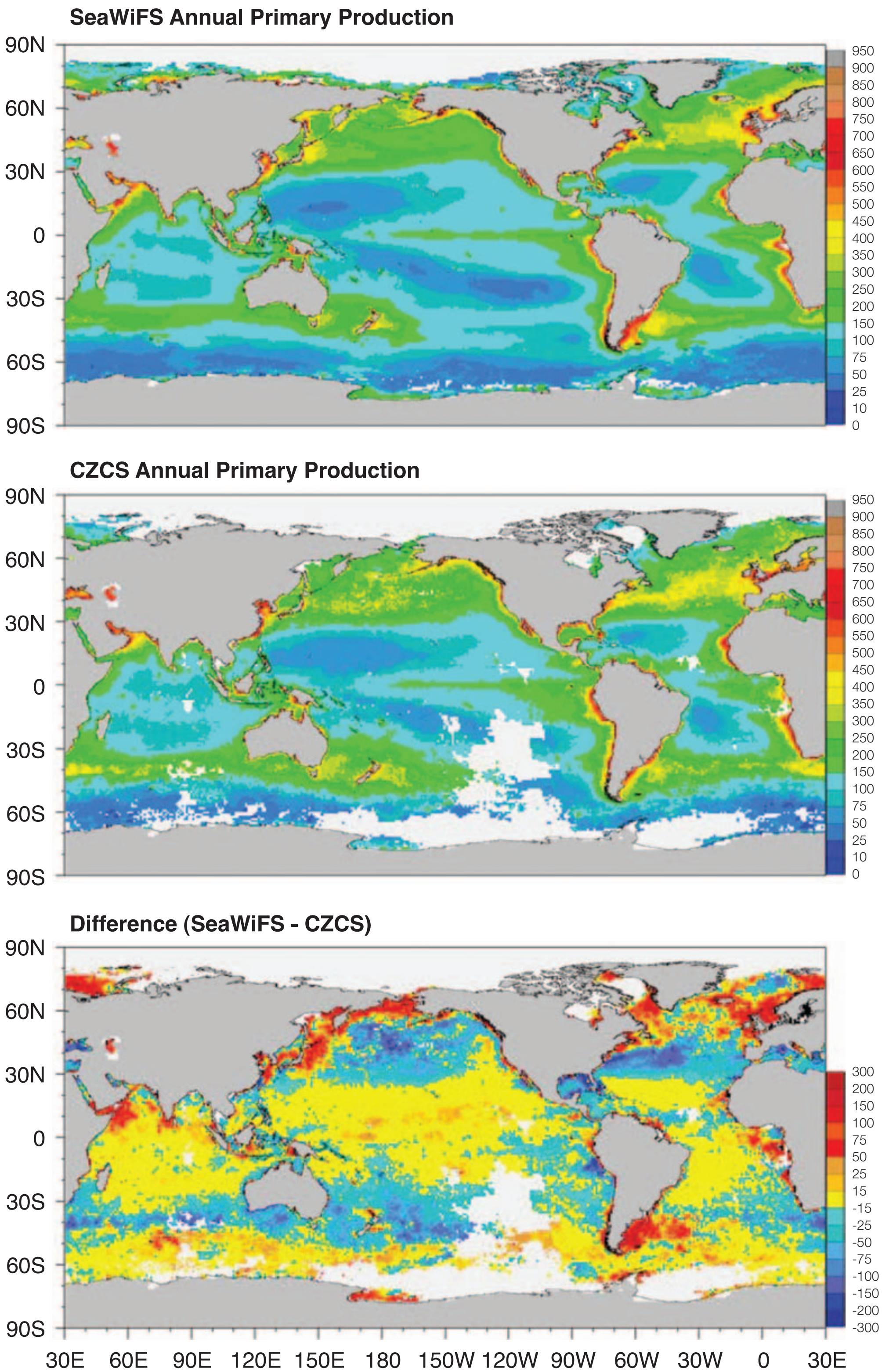


Figure 22:
Change in ocean primary production. Primary production distributions for the SeaWiFS era (1997 to mid-2002), the Coastal Zone Color Scanner era (1979 to mid-1986), and the difference. Units are gC m^{-2} yr^{-1}. White indicates missing data.
Credit: Gregg, W.W., M.E. Conkright, P. Ginoux, J.E. O'Reilly, and N.W. Casey, 2003: Ocean primary production and climate: Global decadal changes. Geophys. Res. Lett., ***30:15****, 1 August 2003.*

time and across many diverse species and geographic regions, that are consistent with what would be predicted by scientific understanding of the physiological tolerances of species to temperature. "Meta-analyses" provide a way to re-analyze and combine results from various studies to determine whether there are underlying consistent shifts.

One such re-analysis, based on observations made in studies of more than 1,700 species, documented significant range shifts averaging 6.1 km per decade towards the poles (or meters per decade upward in altitude) over time scales ranging from 16 to 132 years. The re-analysis found mean advancement of spring events by 2.3 days per decade, over time scales ranging from 17 to 1,000 years. A total of 279 species showed temporal and spatial responses that may be associated with 20th century climate trends. Another re-analysis based on observations made in 143 studies revealed a consistent temperature-related shift, or 'fingerprint,' in species ranging from molluscs to mammals and from grasses to trees. More than 80% of the species that showed changes were shifting in the direction expected on the basis of known physiological constraints of species. The balance of evidence from these studies suggests that impacts of global warming are discernible in animal and plant populations.

Natural resource management to offset greenhouse gas emissions. To help meet the need for identifying how terrestrial ecosystems can be managed to mitigate and adapt to climate change, optimize carbon sequestration, and reduce greenhouse gas emissions, a symposium was held to examine natural resource management opportunities for sequestering atmospheric CO_2 and reducing greenhouse gas emissions across multiple biomes. The scope of the symposium included forest, agriculture, range, boreal, desert, grassland, and wetland systems. Information presented included management options for increased storage of terrestrial carbon; monitoring information on current terrestrial carbon stocks; new and innovative technologies and methodologies for measuring and monitoring greenhouse gases in terrestrial ecosystems; economic projections for alternative carbon sequestration and emissions reduction practices in different terrestrial ecosystems; and policy implications of scientific carbon research findings. Some results presented indicate that nitrous oxide (N_2O) mitigation in cropping systems can be achieved with little or modest yield penalties by better adjusting nitrogen fertilizer additions to crop nitrogen needs. Other presentations described how, on fertile forest sites, or after fertilizer application, carbon sequestration in moderately long-lived carbon pools may be sustainably enhanced.

Effects of climate change on experimental forests. Precipitation amounts and atmospheric composition affected experimental forests in separate field experiments. Full analysis of the first 8 years of an experimental manipulation of precipitation on a deciduous forest ecosystem in Tennessee revealed that changes in precipitation amount affected nutrient cycling and mortality of young trees, but had little influence on large-tree wood or fine root growth, or on litter decomposition. In general, the forest was resilient to altered precipitation amount, but long-term changes in forest species composition could result from changes in hydrology. In another field experiment (in Wisconsin), the postulated stimulation of trembling aspen growth by several years of elevated atmospheric CO_2 concentration (related to fossil fuel use) was approximately offset by a concomitant increase in tropospheric ozone (O_3) concentration (also related to fossil fuel use). These ongoing experiments and related activities are supplying policymakers with empirical data needed to evaluate the potential effects of global change on important ecosystems.

Farmers and ranchers can expect increased atmospheric carbon dioxide to be a mixed blessing. Increased growth and yield are well-known responses of crops to CO_2 enrichment. However, recent research shows that increased CO_2 also can have undesirable effects in agricultural systems. When plots of shortgrass prairie in northeastern Colorado were exposed to twice-ambient CO_2 levels in open-top chambers, the forage produced had less nitrogen and was less digestable than forage produced in ambient-level CO_2. In another experiment, increased CO_2 stimulated the growth of five of the most important species of invasive weeds, more than any other plant species yet studied. This suggests that some weeds could become bigger problems as CO_2 increases. In other studies, at twice the ambient CO_2 level, white clover leaf area consumed by an insect pest (the Western flower thrips) was approximately 90% greater than leaf area consumed in ambient CO_2. Although enriched atmospheric CO_2 could provide some benefits to plants, farmers and ranchers may face some surprises in managing agricultural systems to sustain both yield and quality as CO_2 levels continue to increase.

Interagency ecosystem model-data comparison. A multi-agency effort to evaluate 13 stand-level forest ecosystems models, which varied in spatial, mechanistic, and temporal complexity, was carried out with the use of independent field data. The field data were obtained from eastern Tennessee over an 8-year period using a wide range of methods. No single model consistently performed the best at all time steps or for all variables considered. Inter-model comparisons showed good agreement for water cycle fluxes but considerable disagreement among models for predicted carbon fluxes. The mean of all model outputs was nearly always the best fit to the observations. Models missing key forest components or processes, such as roots or modeled soil water content, were unable to provide accurate predictions of ecosystem responses to short-term drought. Models using hourly time steps, detailed mechanistic processes, and having a realistic spatial representation of the forest ecosystem provided better predictions of observed data. Predictive ability of all models deteriorated under drought conditions, indicating that further research is needed to evaluate and improve ecosystem model performance under unusual conditions, such as drought, that are a common focus of environmental change discussions.

Highlights of FY 2004 and FY 2005 Plans

The CCSP will continue to support research to understand ecosystem processes and their relationship to climate, carbon cycling, and resource management; determine the potential responses of ecosystems to climatic and global change; and identify options for reducing vulnerability and seizing opportunities to enhance resilience and sustain ecosystem goods and services. Key research plans for FY 2004 and FY 2005 follow.

Arctic Climate Impact Assessment. The goal of the Arctic Climate Impact Assessment (ACIA) is to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. The aim is to provide useful and reliable scientific information to governments, organizations, and peoples of the Arctic and of areas influenced by the Arctic, to help them respond to climate variability and change. ACIA will examine possible future impacts on the environment and its living resources, on human health, and on buildings, roads, and other infrastructure. Such an assessment is expected to lead to the development of useful information for the nations of the Arctic region, their economy, resources, and peoples.

The assessment will be open and transparent, and the review of its conclusions is intended to be credible and rigorous. Also, the degree of uncertainty of the conclusions will be made clear. Two scientific volumes will be completed in 2004; the first will be a rigorous peer-reviewed scientific volume, and the second will be an overview document summarizing results in readily understandable language. There is broad participation of experts from many different disciplines, including indigenous cultures, and countries in preparing the assessment. NSF and NOAA have provided much of the funding for this effort.

These activities will address Question 8.1 (first milestone, product, and payoff) of the CCSP Strategic Plan.

Data from field experiments quantifying aboveground and belowground effects of elevated CO_2 concentration on the structure and functioning of agricultural ecosystems. By the end of FY 2005, experiments conducted in Free Air CO_2 Enrichment systems and open-top field chambers will be completed. These experiments will provide data on effects of carbon dioxide enrichment—alone and in combination with other environmental characteristics such as water availability, soil fertility, pest pressure, and tropospheric ozone—on crop growth and yield development, root development, carbon sequestration, nutrient cycling, and other processes. Results will be available for modelers to improve projections of crop production and carbon sequestration under different environmental scenarios projected for the 21st century. Crop production estimates will be useful to investigations of the impact of global change on food security.

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

Prediction of location and ecological impact of invasive weeds. By the end of FY 2004 an on-line system will be developed that combines remotely sensed data from Earth observing satellites with ground data provided by local users to generate projections of areas most likely to be changed through the incursion of certain non-native invasive plant species. The system will generate projections through analysis of geospatial and statistical data. These projections can help resource managers develop approaches for the control of invasive species.

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

Fire forecasting, fuels management, and ecosystem carbon storage. Hazardous fuels in forests in the western United States have increased to catastrophic levels due to fire suppression policies and lack of active management. Recent research and observations, however, suggest that fuels have also increased due to a sudden ocean-climate 'regime shift' in the Pacific Decadal Variability in the mid-1970s. Mapped Atmosphere-Plant-Soil-System (MAPSS) researchers have constructed a simulation technology to forecast ecosystem and fire responses to climatic variations and change. Simulations using seven assumed future climate scenarios suggest that the U.S. Southeast will experience increased fire risk in the coming decades. From FY 2004 through FY 2005, the model will be tested against historical records, and is expected to produce national-scale, high-resolution forecasts of fire risks in the United States that incorporate climate-driven year-to-year changes in fuel loadings and moisture characteristics (see Figure 23). Additional efforts will focus on incorporating insect and disease interactions and management actions into the model, and forecasting risks and locations of future fires.

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

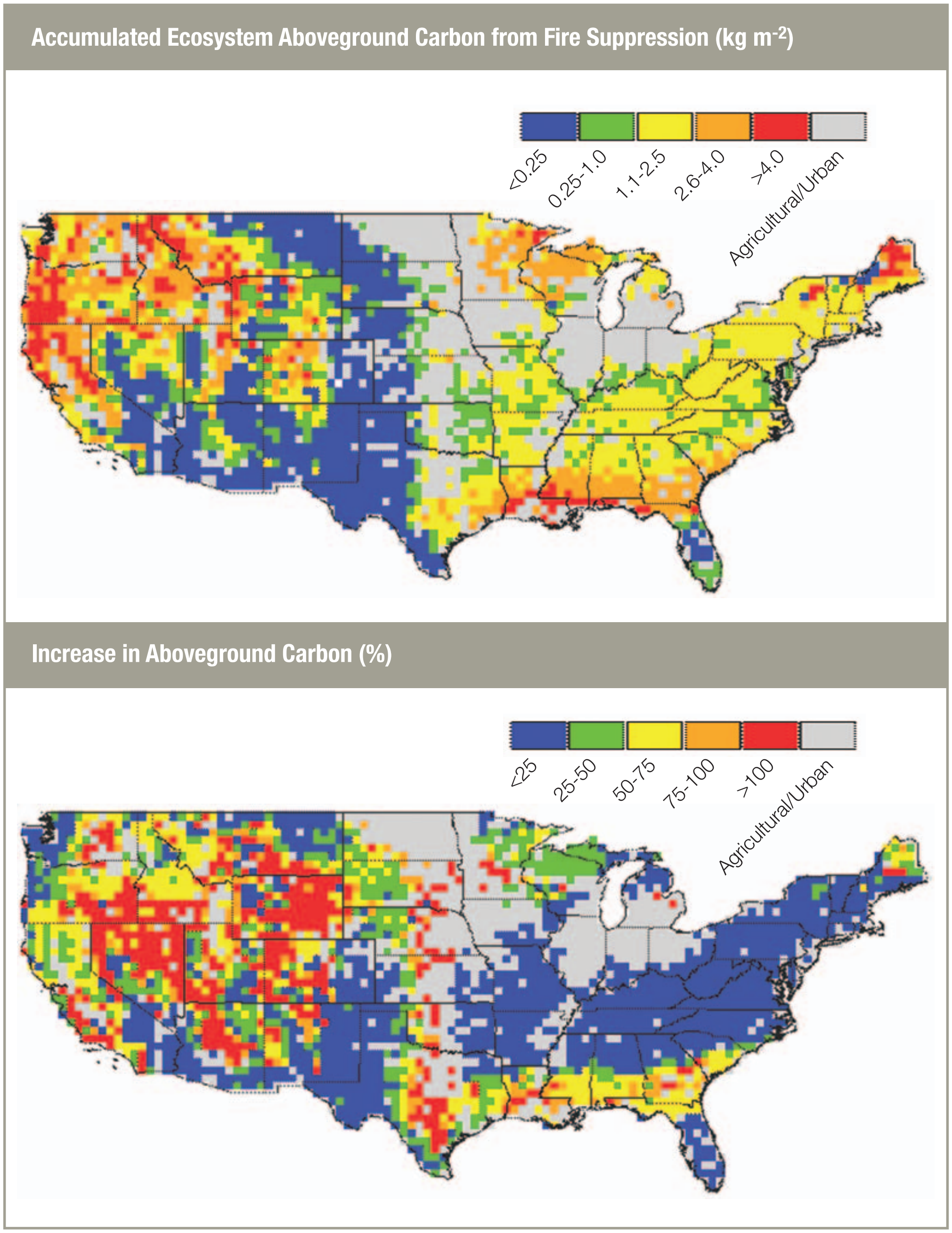


Figure 23: Simulated increase in total aboveground carbon (kg m^{-2}) due to fire suppression by the end of 2003. The map represents the first estimate of the amounts and locations of accumulated carbon in ecosystems as a direct result of over 50 years of fire suppression. The MC1 Dynamic General Vegetation Model is being used as a tool for forecasting wildfire over the course of the next 7 months, updated each month. Historical records show a dramatic drop in the area of wildfire over the United States, due to fire suppression, since the early 1950s. Although the map should be treated as an hypothesis to be tested, it does suggest areas that could be at risk of increased wildfire intensity due to fuels accumulation. However, historical simulations also underscore that interannual and interdecadal climatic variability are significant causes of recent increases in U.S. fire area. *Credit: James M. Lenihan, MAPSS Team, Pacific Northwest Research Station, USDA Forest Service.*

Quantifying effects of warming on boreal forests. Construction of a unique field facility will be completed to study effects of experimental warming on the structure and functioning of a boreal black spruce ecosystem. The facility, involving large open-top chambers combined with belowground temperature control, will be operational by early FY 2004. A long-term study of controlled manipulation of

temperature on ecosystem processes will be initiated during FY 2004. This facility and the experiments conducted in it will provide policymakers with unique data concerning possible effects of Northern Hemisphere warming on goods and services provided by boreal forests.

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

Funding for three new marine Long Term Ecosystem Research (LTER) sites in coastal waters. In FY 2005, funding will be provided for three new marine LTER sites in coastal waters. Funding for the sites that are selected will be for up to 6 years with additional 5-year renewal possible. Such work will initiate collection of the long-term data sets in coastal waters that are needed for the study of possible impacts of climate variability and change on marine ecosystems and marine resources.

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

Quantifying effects of altered temperature and precipitation on soil bacterial and microfaunal communities as mediated by biological soil crusts. About 30% of lands both globally and in the United States consist of semi-arid or arid landscapes. Soil surfaces in these landscapes are covered by biological soil crusts composed primarily of cyanobacteria, lichens, and mosses. Because these crusts cover almost the entire soil surface, most atmospheric inputs of water, nutrients, and solar radiation to soils are mediated by the soil crust community. Bacteria in lichen and cyanobacterial crusts are diazotrophic and photosynthetic, making crusts a dominant source of fixed nitrogen and an important source of fixed carbon in arid land soils. By the end of FY 2005, a series of manipulative and "natural" field experiments carried out across agencies will be used to test hypotheses that increased temperature and seasonal shifts in precipitation will:

1) Alter respiration, photosynthesis, and nitrogen-fixation rates in lichen- and/or cyanobacterially dominated crusts from cool (Colorado Plateau) and/or hot (Chihuahuan) deserts

2) Affect the composition of soil bacterial communities (cyanobacteria, N_2-fixing, and NH_3-oxidizing bacteria) within and beneath soil crusts
3) Change the abundance and composition of soil microfauna (nematodes, mites, collembolans, and protozoa) that serve as a nutritional link between crust inputs and vascular plants
4) Through changes in the soil food web and soil chemistry, indirectly alter growth and nutrient availability to vascular plants.

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

Analyzing the potential effects of climate change and land-use change on selected watersheds. Water quality and quantity in rivers and streams can be affected by changes in temperature and in the timing, amount, and seasonality of precipitation. By the end of FY 2005, an analysis will be completed that examines the potential effects of climate change and land-use change on selected watersheds at varying scales. This analysis will address methodological approaches, stakeholder engagement, and methods employed for characterizing and communicating uncertainties.

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

Quantifying impacts of livestock grazing management on carbon and nitrogen cycling. Measurements will be conducted during FY 2004 and FY 2005 on pastures that have been under different cattle grazing pressures for several years. Data will include year-round micrometeorological measurements of water and CO_2 fluxes, seasonal characteristics of the plant community and soil chemistry, and satellite imagery to relate fluxes and plant attributes.

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

Linking a forest process model with a gap simulation model to refine estimates of forest growth under changing climate. Using known tree species attributes, climate scenarios, and other environmental factors as parameters, the PnET-II forest productivity model (developed at the University of New Hampshire) predicts net primary productivity (NPP) for a given set of conditions. NPP is then used as a parameter in the gap model, which interacts with SRTS, the economic model, on an annual time step. Currently, PnET-II is used with one species at a time, so multiple runs are performed to provide results for various species. The NPP estimates from each species run are then used in the gap model to predict forest stand dynamics. In FY 2004 and FY 2005, work will focus on fully integrating and linking these models.

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

Quantifying climate change impacts on forest and rangeland vegetation, species shifts, and ecosystem productivity. Forest and rangeland vegetation, the geographic distribution of plant and animal species, and the productivity of these ecosystems is strongly influenced by the amount of rainfall and snow, the temperatures, the length of the growing season, and many other factors of the local climate. Identifying the vulnerabilities of ecosystems and economies to climate variability and change depends on an understanding of the sensitivity of those systems to climate. In FY 2004 and FY 2005, field and simulation studies will be employed to explore and evaluate the impact of changes in climate on forest and rangeland ecosystems in areas of the western United States.

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