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 provide goods (e.g., food, fiber, fuel, pharmaceutical products) and services (e.g., the cycling of water and nutrients, the regulation of weather and climate, the removal of waste products, natural beauty, sustaining biological diversity) to society. Global change—including land-use change and climate change, as well as other environmental change such as habitat fragmentation, the spread of invasive species, and pollution—is affecting the ability of these life support systems to sustain the goods and services required by our growing population. Therefore, it is important to focus research on furthering our understanding of ecosystem processes, including the interactions of ecosystems with the atmosphere and physical climate system as well as the effects of human activities on ecosystems. The goal of the ecosystems research element is to understand and project the potential effects of global change on ecosystems, the goods and services ecosystems provide, and ecosystem links to the climate system. This improved understanding leads to better management practices because of the ability to anticipate longer term ecosystem effects.

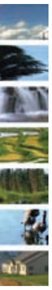
In FY 2007, one research focus for the CCSP Ecosystems Interagency Working Group (EIWG) is to increase understanding of the relationship between climate variability and change and ecosystem net primary production and biodiversity. Topics of emphasis are societally important ecosystems and regions where near-term abrupt environmental changes may occur. A central element of this effort will be the ongoing development and improvement of predictive models that operate across spatial scales to enable ecological forecasting for aquatic and terrestrial ecosystems. Research conducted by CCSP member agencies continues to improve our understanding of the drivers and impacts of climate variability and change. The challenge for the EIWG lies in furthering our understanding of the relationship of these drivers and impacts to ecological processes, which will ultimately require the linking, if not direct coupling, of geophysical climate models with ecosystem models.

This EIWG effort contributes to all five CCSP Goals with an emphasis on Goal 4. It also directly addresses the CCSP ecosystems research element questions 8.1, 8.2, and 8.3. Strong synergies and interactions exist with other CCSP research elements, including, but not limited to, the climate variability and change, water cycle, carbon cycle, and land-use/land-cover change research elements.

Successful research and application require collaboration across agencies, as well as ongoing input from scientists within and outside the Federal government. The participating agencies of the EIWG work collaboratively in research program oversight and execution as described in the *CCSP Strategic Plan*. Many of the research accomplishments and plans described in this chapter represent the joint efforts of multiple agencies and/or the work of agencies and their external partners and cooperators. The EIWG engages the research community in providing input and feedback on its plans.

HIGHLIGHTS OF RECENT ACTIVITIES

Priority Setting for Ecosystems Research in CCSP Workshop Report.[10] A non-Federal writing team has published *Ecosystems and Climate Change: Research Priorities for the U.S. Climate Change Science Program: Recommendations from the Scientific Community*, a report of the EIWG workshop held in 2004. More than 70 scientists came together in the workshop to identify and discuss priorities and approaches for the Ecosystems chapter (Chapter 8) of the *CCSP Strategic Plan*. The authors used the presentations and breakout summaries to develop recommendations and insights for the EIWG to use in program development. The report concludes that Chapter 8 in the *CCSP Strategic Plan* provides a good foundation and establishes boundary conditions for ecosystems research. General themes included the need to improve observation systems; use more large-scale experiments; integrate models using monitoring data, observations, and experimental data; and communicate results and uncertainties to policymakers and resource managers. A central recurring theme was the need to develop better mechanistic understandings of ecosystem processes, including interactions of ecosystems with the atmosphere, climate, and human activities, to better model and increase our confidence in predictions of ecosystem responses and feedbacks to global changes.



Positive Feedback Effect of Arctic Warming: Shrub and Tree Expansion into Snow-Free Areas.[4] As concentrations of greenhouse gases in the atmosphere increase, a major challenge to predicting Earth's future climate is understanding how various feedbacks alter the contribution of greenhouse gases to climate change. Synthetic analysis of field data collected in arctic Alaska show that summer changes in the reflectivity (albedo) of arctic terrestrial environments contribute substantially to observed recent warming in the Arctic. Specifically, recent pronounced terrestrial summer warming in arctic Alaska correlates with a lengthening of the snow-free season, amplifying global warming in the Arctic through a positive feedback mechanism involving reduced snow cover (highly reflective)—the main cause of summer warming observed to date—and expanding shrub and tree cover, which is likely to contribute disproportionately to future summer warming. As a result, atmospheric heating has increased by approximately $3\ \mathrm{Wm}^{-2}$ per decade—a value similar to the regional heating expected over multiple decades from a doubling of atmospheric CO_2. Calculations show that 11,600 km^2 has been converted from tundra to forest in the last 50 years, representing 2.3% of the Arctic's treeless area. Current general circulation models include the positive feedbacks of reduced snow cover on global warming, but not the additional feedbacks caused by changes in vegetation, which could raise seasonal temperatures by an additional 1.1 to 1.6°C (see Figure 36).

Productive Forests May Respond Most Rapidly to Global Change.[14] Forests provide humans with irreplaceable goods and services and sequester the majority of the terrestrial biosphere's carbon, making them key components of the global carbon cycle. Trees in the world's most productive forests—forests that add the most new growth each year—tend to die at a younger age than trees in less productive forests. This discovery, based on a compilation and analysis of results from hundreds of long-term studies worldwide, could help scientists predict how forests will respond to ongoing and future environmental changes. Recent analyses of these data demonstrated that forest turnover rates (birth and death rates of trees) vary directly in parallel with global and regional patterns of forest productivity. Half of all trees in tropical forests growing on rich soils die and are replaced by new trees in just 30 years. In comparison,

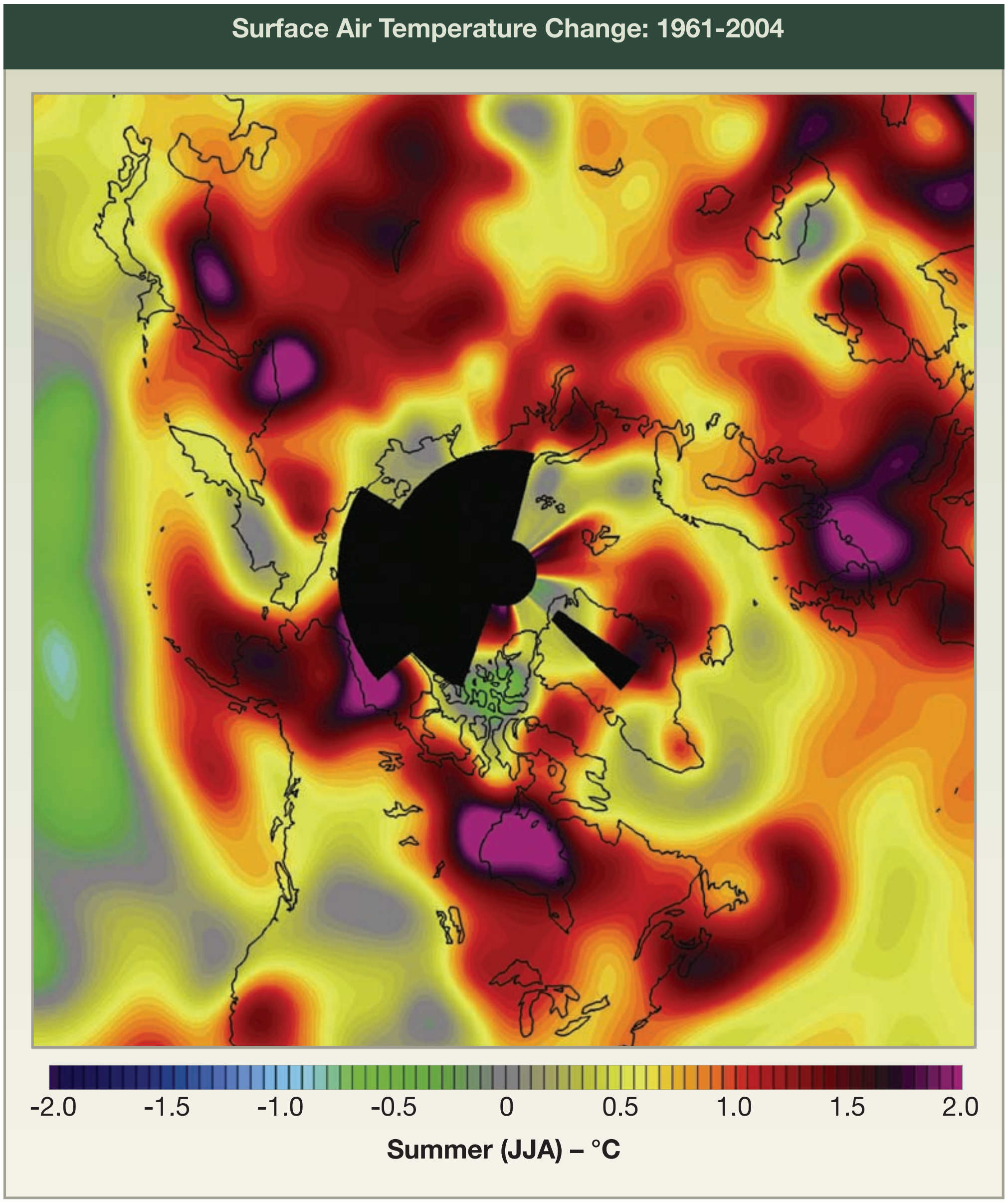


Figure 36: Surface Air Temperature Change: 1961-2004. This product provides the spatial pattern of high-latitude summer (June to August) surface warming (in °C over 44 years, 1961 to 2004). The pattern of temperature increase was estimated from monthly anomalies of surface air temperature from land and sea stations throughout the Northern Hemisphere, updated from Chapman and Walsh (1993). *Credit: F.S. Chapin, III, University of Alaska–Fairbanks (reproduced with permission from* **Science***).*

a century or more can pass before half of the trees die and are replaced in coniferous forests growing at high latitudes. Implications of more rapid turnover in tree populations include: 1) The world's most productive forests may be those that are likely to respond most quickly to future environmental changes such as climate change; 2) environmental changes that increase the productivity of a given forest could also lead to more rapid turnover of trees, decreasing the average age of trees in that forest; 3) other environmental changes that increase forest productivity (e.g., nitrogen deposition) may also increase forest turnover rates, leading to forests that are more heavily dominated by younger and smaller trees, with potential effects on wildlife and biodiversity; 4) managers wishing to establish forest-monitoring programs for change detection may wish to devote extra effort toward monitoring their most productive forest types; and 5) increased dominance by younger trees could lead to changes in the amount of carbon sequestered or stored by forests. Given the central importance of forests to the global carbon cycle (hence also to global climate change), and the increasing importance of carbon storage to international treaties and trading of carbon credits, it is important to develop a solid understanding of the relationships among forest productivity, turnover, and carbon storage. This study is among the first to shed light on these relationships.

Invasive Species Alter Ecosystem Biogeochemistry in Hawaii Volcanoes National Park.[1] Using imagery from the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) sensor, researchers at the Carnegie Institution and Stanford University have documented the impacts of two invasive species, the nitrogen-fixing tree *Myrica faya* and the understory herb *Hedychium gardnerianum*, on the water content and nitrogen balance in the montane rain forest of Hawaii Volcanoes National Park. These impacts leave a spectral signal at the top of the tree canopy, which is detectable by AVIRIS. The park landscape is young, and the low nitrogen content of its volcanic soils limits forest productivity, leaving a native *Metrosideros polymorpha* forest canopy that is low in nitrogen and water content.

The invasive species are driving fundamental changes in ecosystem properties. *Myrica faya* fixes nitrogen from the atmosphere, a capacity the native trees lack. Its canopy is high in nitrogen, and has higher water content. Higher ecosystem nitrogen concentrations have led to faster leaf turnover, higher rates of nutrient cycling, faster decomposition, greater nitrogen availability, greater fluxes of nitrogen-containing trace gases, and ultimately invasion by other nutrient-demanding species. While the impacts of the tree *Myrica faya* occur at the canopy level and thus allow direct detection by remote-sensing systems, locating the understory herb *Hedychium gardnerianum* within the heavy forest is also possible due to its significant effects on nitrogen and water levels in the canopy vegetation above it. Classification of the entire park area based on canopy chemistry shows that *Myrica* now dominates 28% of the landscape and an additional 23% is undergoing transformation, with *Myrica* growing into the canopy. Up to 13% of the remaining native forest is infested with *Hedychium*. The canopy nitrogen content of the entire region has doubled as a result of the invasion of *Myrica*, while the effects of *Hedychium* are only beginning to be investigated. Park managers are using the results from this initial study for planning and control of invasive species. The researchers are also trying to expand the study to include additional invasive species that maintain unique biochemical properties observable from imaging spectroscopy. This work documents the ability of invasive species to alter ecosystems in fundamental ways by not only changing the composition and relative abundance of species but also by dramatically affecting how these systems cycle water and elements vital for life.

Wood Compression Strength Loss as an Index of Organic Matter Decomposition in Boreal Forest Mineral Soil.[7] Organic matter decomposition is used in climate change models to assess the possible impacts of temperature increases on soil carbon in high-latitude (>50°N) boreal forests. Decomposition studies in this region have mostly focused on surface litter, but very few have investigated organic matter decomposition in mineral soil as a function of different climates. A 3-year field study in six Scots pine plantations along a north-south temperature gradient from Finland to Poland showed that radial compression strength loss was a good index of wood decomposition. Compression strength losses in wood stakes ranged from 20% in northern Finland to 94% in central Poland, which corresponded to dry weight reductions of 3 and 65%, respectively. The compression strength test was a more sensitive indicator of wood decomposition in colder Finnish soils, which had no stake weight loss at most soil depths after 3 years. Both compression strength loss and weight loss decreased as soil depth increased, which likely reflect lower mineral soil temperatures. Chemical analysis of the wood stakes showed a progressive proportional decrease in lignin, cellulose, and hemicellulose content with total weight and carbon loss. In contrast, wood nitrogen concentration and content increased as decay progressed. Results of these studies in Europe indicate that wood stakes can be used to measure organic matter decomposition in mineral soil across a range of climate conditions or as climate changes.

Integrating the Effects of Land Use and Global Climate Change on Hydrology and Vegetation of Northern Great Plains Wetlands.[6] The Prairie Pothole Region (PPR) in central North America contains millions of glacially formed, depressional wetlands embedded in a matrix of native grassland and agriculture (see Figure 37). These wetlands provide valuable ecosystem services to human populations, and represent the single most productive habitat for waterfowl in the world. Wetland availability and emergent cover conditions are the primary factors that

Figure 37: The Prairie Pothole Region. This photograph provides an aerial view of glacially formed, depressional wetlands embedded in a matrix of native grassland and agriculture, located in the Prairie Pothole Region of central North America. Recent research based on possible future climate scenarios suggests that these wetlands and their ability to support breeding waterfowl will be altered. *Credit: J. Ringleman, Ducks Unlimited.*

determine the number and diversity of breeding waterfowl that will settle in the PPR. The well-established sensitivity of prairie wetlands to climate variability portends a similarly sensitive response to future climate change. Climatic fluctuations drive hydrology that in turn drives key processes in prairie wetlands. This project was initiated to quantify how these wetland systems respond to climatic oscillations at regional scales and to develop simulation models to forecast wetland responses to future climatic change. The broad spatial and temporal responses across the PPR in terms of climate, wetland water levels, and vegetation were explored by applying a wetland simulation model. Model simulations suggest that the most productive habitat for breeding waterfowl would shift under a drier climate from the historic center of the PPR in the Dakotas and southeastern Saskatchewan to the wetter eastern and northern fringes, areas that are currently less productive or where the majority of wetlands have been drained. Based on these results, unless wetlands in these fringe areas of the PPR are protected and restored, there is little insurance for waterfowl in the region if faced with future climate warming. Results suggest a significant shift in the efforts of wetland managers and where future restoration dollars should be spent in an uncertain climate future.

Rising Atmospheric Carbon Dioxide May Alter Rangeland Quality.[12,15] Rangelands are an important managed ecosystem in North America, providing food and fiber to large animal populations. Long-term results from the USDA Rangeland Resource Unit indicate that although rising atmospheric CO_2 can enhance forage

production of shortgrass prairie, it results in lower quality forage that can degrade animal performance. Cheatgrass is a recognized invasive annual weed of ecosystems in the western United States that reduces fire return times from decades to less than 5 years. Results from the USDA Crop Systems and Global Change Unit indicate that increases in atmospheric CO_2 during the 20th century have been sufficient to increase aboveground biomass of this invasive species by 1.5 to 2.7 g per plant for every 10 parts per million (ppm) increase in CO_2 above the 270-ppm pre-industrial baseline. These data suggest that increasing atmospheric CO_2 may have contributed significantly to cheatgrass productivity and fuel load with subsequent effects on fire frequency and intensity.

Warming May be Causing Decline of Biological Soil Crusts in Semi-Arid Ecosystems.[3] Drylands, including deserts, shrublands, savannas, and woodlands, represent about 35% of U.S. land area. Biological soil crusts are the dominant living soil cover in many of these ecosystems, and are critical for nitrogen (through atmospheric molecular nitrogen assimilation) and carbon inputs to soils. These inputs support soil food webs and the mineral nutrition of vascular plants. Biological crusts also contribute to soil stability (reducing erosion) and water infiltration, and provide important local environments for seed germination. Monitoring in a semi-arid grassland in Utah that

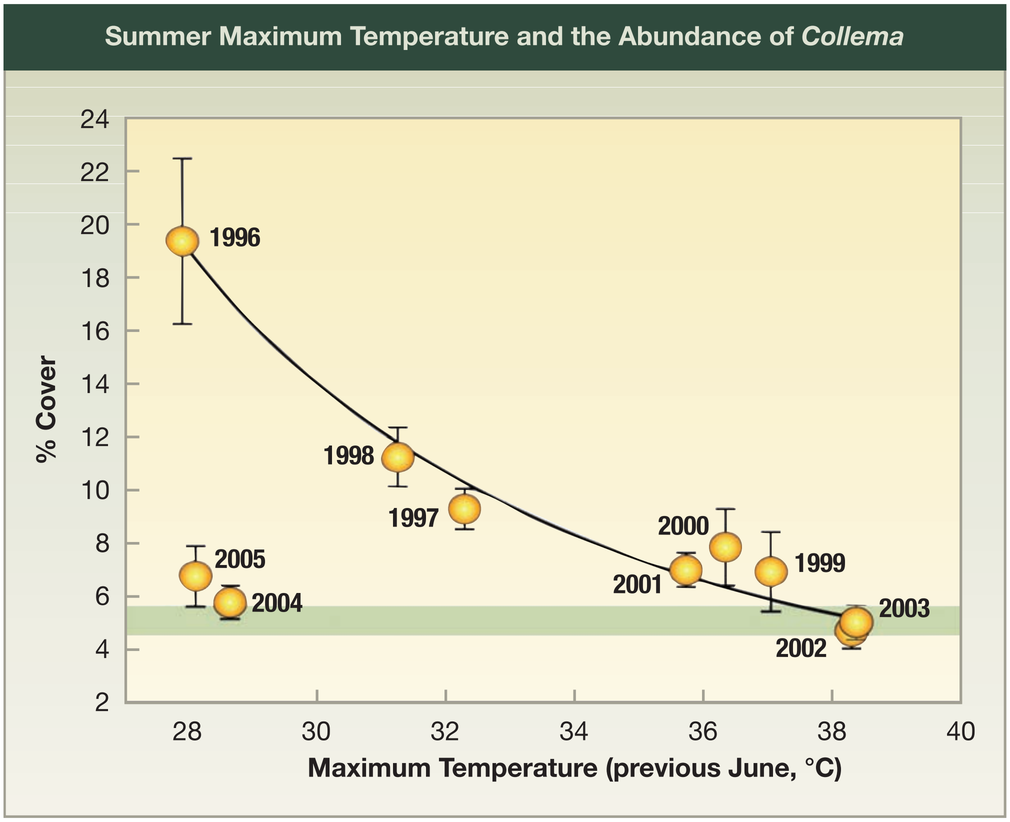
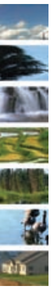


Figure 38: Summer Maximum Temperature and the Abundance of *Collema*. A negative correlation existed between summer maximum temperature (mean daily maximum temperature during June) and subsequent abundance of the lichen *Collema*, which dominates the biological soil crust in many semi-arid western ecosystems. Even after 2 cooler years, the lichen had not recovered from the warm period of 1997 to 2003. *Credit: J. Belnap, S.L. Phillips, and T.T. Troxler, U.S. Geological Survey.*

is protected from human disturbance indicates that the dominant lichen in the soil crust, *Collema*, was detrimentally affected by the unusually warm summers between 1996 and 2003 (see Figure 38). The cooler summers of 2004 and 2005 produced limited recovery of *Collema* populations. These results indicate that warming in the arid and semi-arid west has the potential to rapidly alter the abundance of ecologically important organisms. This observation is being tested by experimentally warming field plots and quantifying the effects on plant communities and the biological soil crusts supporting them.



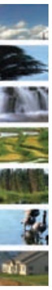
Rising Atmospheric Carbon Dioxide Concentration May Counteract Detrimental Effects of Increased Ozone Pollution on Tree Growth.[8,9] Research at the DOE Free-Air CO_2 Enrichment (FACE) facility near Rhinelander, Wisconsin, is determining possible effects of rising concentrations of CO_2 and ozone (O_3) in the lower atmosphere on the growth (accumulated living biomass) of northern hardwood tree stands. After 6 years of treatments using concentrations of O_3 projected for the year 2050 (i.e., 50% greater than today), total biomass of aspen stands, aspen-birch mixtures, and aspen-maple mixtures was reduced by 23, 13, and 14%, respectively. However, when the elevated O_3 treatment was combined with the CO_2 concentration projected for the year 2050 (i.e., 560 ppm), the aspen biomass was only 8% lower compared to stands growing in the present ambient atmosphere. Moreover, the accumulated biomass of the aspen-birch and aspen-maple mixtures was stimulated (8 and 24%, respectively) by the combination of elevated CO_2 and elevated O_3 relative to the present ambient atmosphere. The results emphasize the importance of studying multiple changes in the environment rather than single (isolated) factors only, and indicate the importance of species-specific effects of environmental change.

Transfer of Carbon to Adjacent Aquatic Ecosystems in Enhanced Carbon Dioxide Studies.[11] Carbon export from wetlands to estuaries is quantitatively important at ambient CO_2 levels. Study results suggest that elevated atmospheric CO_2 concentrations may increase carbon export from some tidal marshes to estuaries. In a long-term tidal marsh experiment, elevated CO_2 increased soil-water concentrations of dissolved inorganic carbon by 27% at 30-cm depth. The elevated CO_2 treatment also increased concentrations of dissolved organic carbon and methane, but by less significant amounts (15 to 27% and 12 to 18%, respectively). This is important because the export of

inorganic and organic carbon from tidal marsh soils affects the chemistry and productivity of adjacent estuaries. The study is among the first to suggest that elevated CO_2-enhanced metabolism in terrestrial systems may indirectly influence water quality and metabolism in adjacent aquatic ecosystems.

Impacts of Climate Change on the Success of Watershed-Scale Restoration Strategies in Puget Sound.[2,13] Landscape-scale watershed planning efforts aimed at restoring the structure and function of river basins are ubiquitous across the country. Motivations for these restoration efforts typically include maintaining and improving water flows and water quality and recovering imperiled species. This project involved developing models of climate impacts in the western United States, where considerable resources have been devoted to designing large-scale habitat restoration plans to bolster water quantity and promote recovery of salmon and other aquatic species. Most models predicting the ecological outcomes of such restoration plans do not include the potential effects of multiple environmental changes in forecasting possible outcomes. In particular, future climate is likely to affect several important determinants of habitat quality and quantity, including seasonal flow rates and water temperature. A loosely linked system of process-based models of climate, hydrology, and salmon population dynamics was used to examine the possible effects of climate change over the next 50 years on freshwater habitat conditions in the Snohomish River Basin in western Washington.

The project also explored how predicted impacts of habitat restoration strategies on salmon are likely to differ when climate change impacts on habitat are included in predictions of future chinook salmon response. Meteorological output from two global climate models was downscaled and used to drive a streamflow and temperature model, the output of which was used to drive a salmon life cycle model. Model results suggest that climate change will cause increased winter peak streamflow, decreased summer flow, and increased water temperature throughout the year, all of which are likely to have negative effects on salmon survival and reproduction. The two climate models used in the study project different seasonal patterns of rainfall, which has a large impact on the magnitude of predicted salmon population declines, suggesting a substantial degree of inherent unpredictability in the projection of climate change effects on freshwater systems. Model projections suggest that climate change in this basin may cause 14 to 38% declines in salmon populations. The concurrent changes in stream habitats due to planned habitat and land-use restoration actions are likely to lessen the salmon declines, but meeting population recovery targets adopted for salmon, and water quantity demands for agricultural, urban, and other rural uses, is likely to be much more difficult in the face of climate change (see Figure 39).



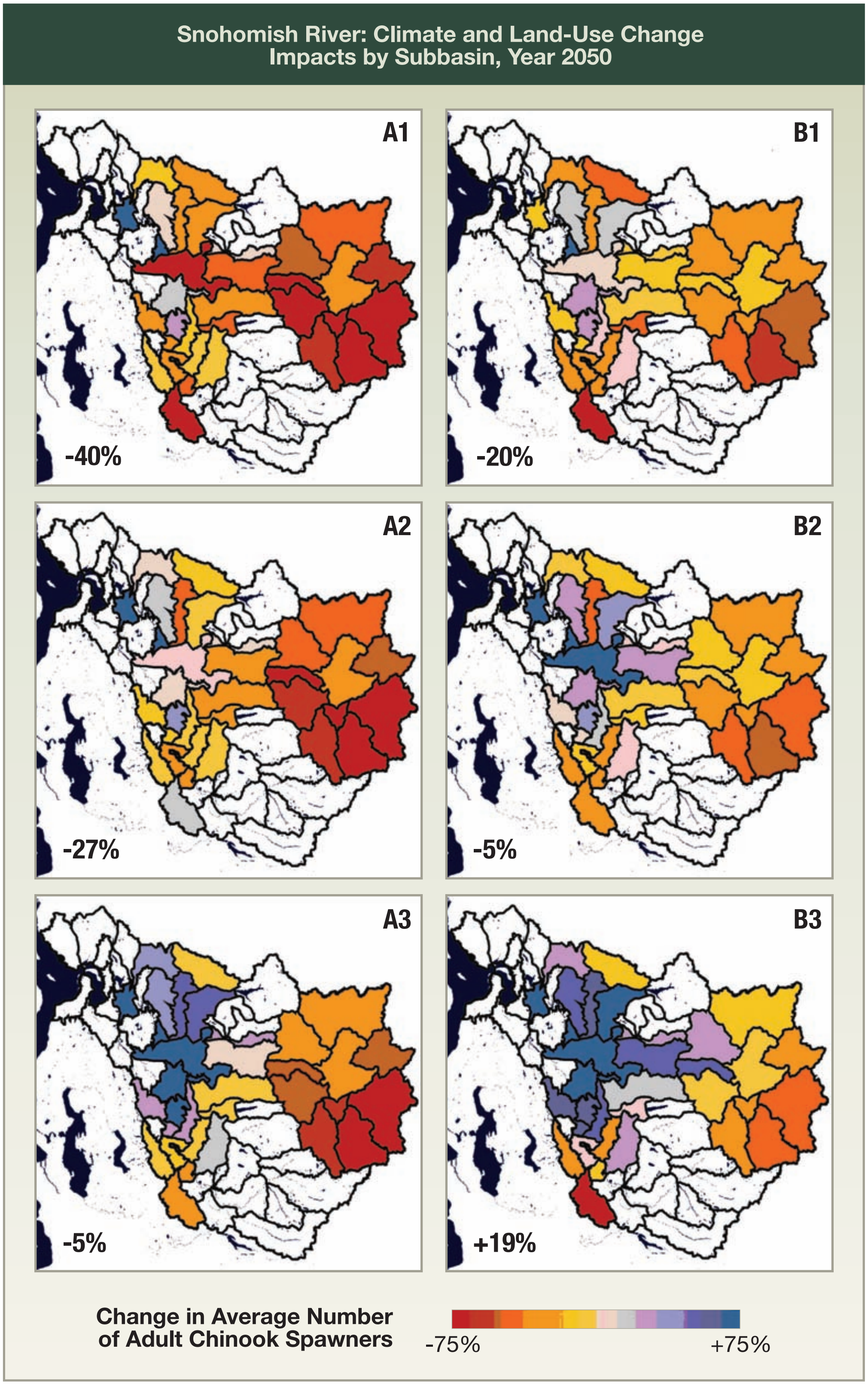
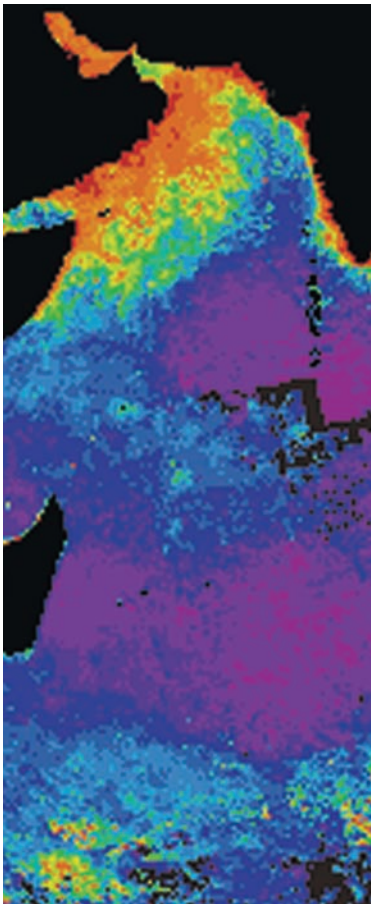


Figure 39: Snohomish River: Climate and Land-Use Change Impacts by Subbasin, Year 2050. This graphic provides the projected change in abundance of spawning Chinook salmon between 2000 and 2050 under two scenarios of future climate and three scenarios of future land use. The panels in column A are based on downscaled predictions of the GFDL_R30 climate model; column B is based on the HadCM3 climate model. Row 1 features current (2001) land use; row 2 features a scenario including a moderate amount of habitat restoration; and row 3 features a scenario in which the restoration plan for the basin is fully implemented. The number in the lower left corner of each panel indicates basin-wide total change in abundance. *Credit: M.W. Wiley, University of Washington.*

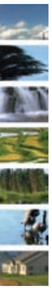
Warming of the Eurasian Landmass Making the Arabian Sea More Productive.[5] Scientists have used NASA data from ocean color satellites to show that phytoplankton concentrations in the western Arabian Sea have increased by more than 350% over the past 7 years. This increase in phytoplankton coincided with satellite observations of a decrease in snow cover in Eurasia. Since 1997, the decline in snow cover has caused a land-ocean thermal gradient that is particularly favorable to stronger southwest (summer) monsoon winds. The sea surface winds have been strengthening over the western Arabian Sea resulting in stronger monsoon winds and accompanied by enhanced upwelling. The strengthened upwelling is the source of the nutrients causing the blooms. While blooms of phytoplankton can enhance fisheries, they could be detrimental to the local ecosystems, causing eutrophication and oxygen depletion (hypoxia or anoxia) that could lead to a decline in fish populations and the production of chemically relevant trace gases such as nitrous oxide (see Figure 40).



HIGHLIGHTS OF FY 2007 PLANS

Models of Terrestrial Ecosystems. An important aspect of better understanding the relationship between ecosystems and climate change is establishing and modeling impacts and feedback. Efforts are focused on combining observations, inventory, and experimental data into ecological models coupled with regional and global climate prediction models. A number of projects focused on improving and coupling such models are part of CCSP-sponsored research efforts:

- *Mountain Ecosystems*. A landscape disturbance model will be used to predict responses of western mountain ecosystems to combinations of climate change and altered fire regimes. This approach will provide linkages between broad-scale climate variability and wildfires, and will become the basis for forecasting extreme wildfire years through empirical models using annual and decadal climate variability data.
- *Forests*. A satellite-derived vegetation index for tree species will be developed using USDA Forest Service Forest Inventory and Analysis national forest inventory data



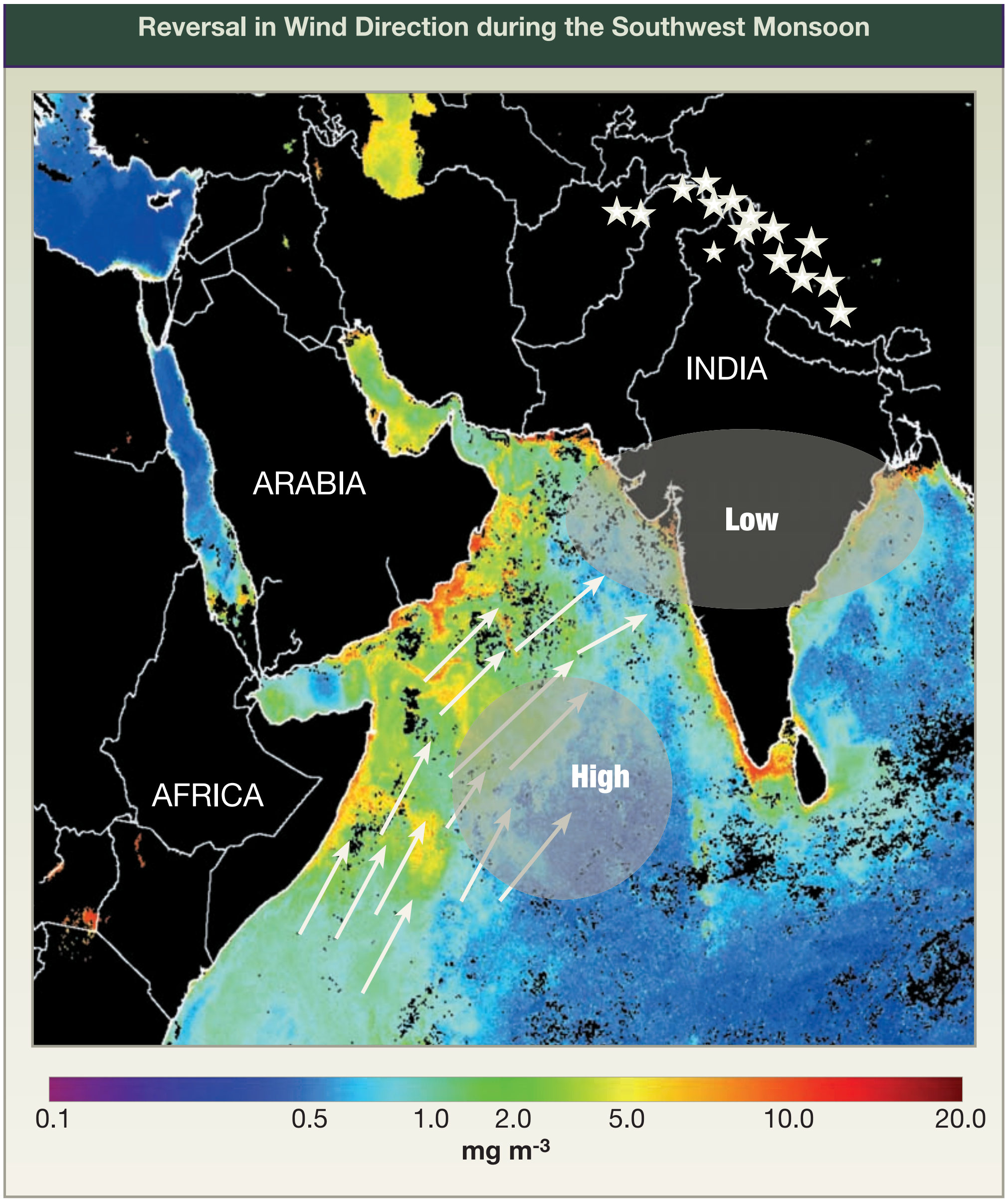

Reversal in Wind Direction during the Southwest Monsoon

Figure 40: Reversal in Wind Direction during the Southwest Monsoon. This schematic shows the reversal in wind direction during the southwestern monsoon (June to September) resulting from changes in the land-sea pressure gradient. *Credit: J.I. Goes, Bigelow Laboratory for Ocean Sciences.*

and enhanced NASA satellite vegetation data. The study will cover 65 U.S. ecoregions and will explore the relationship between productivity and diversity at regional to national scales. Repeated surveys will provide information about the impacts of a changing climate on productivity.

- *Watersheds*. Regional assessments have shown potential impacts on water resources due to the feedbacks between land use and climate change. A review of public watersheds will provide information about current decisionmaking practices and help prioritize science needs and watersheds most likely to be affected.

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 and are being coordinated with other working groups.

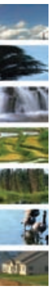
These activities will address Questions 6.2, 8.1, 8.2, 8.3, and 9.2 of the CCSP Strategic Plan.

Terrestrial Ecosystem Research. Terrestrial ecosystems research priorities in FY 2007 follow:

- *Soils*. A genetic signature from soil microorganisms will be used to develop an understanding of the mechanisms that control nitrous oxide flux from soil. This knowledge will be used to better predict nitrous oxide concentrations in the atmosphere under changing precipitation resulting from different climatic conditions.
- *Long-Term Ecological Research Sites*. Long-Term Ecological Research sites provide substantial laboratories for developing an understanding of global change impacts on a variety of ecosystems. Ten sites are under review for renewal and will be evaluated for their contributions to improved understanding and management of ecosystems under a changing environment.
- *Species Invasion of Ecosystems*. The existing science related to species invasions associated with global change and their impacts on ecosystems will be evaluated. Invasive species are one of the primary threats to ecosystems and biodiversity. More information is needed to better monitor and adapt existing management practices to help reduce impacts.
- *Forest Markets and Trends*. Fifty-year projections of future regional forest markets and trends in forest conditions under alternative climate assumptions will be developed. The projections will look at modified growth rates and the geographic distribution of forests in North America. This information will be useful for policymakers concerned with the long-term implications of climate change on the Nation's forest ecosystems.
- *Food Security*. Food security requires the ability to predict accurately crop-pest relationships in a changing environment. Studies are underway to address the possible impacts of climate change and atmospheric CO_2 on pest biology. Specifically, the direct effects of CO_2 and concomitant changes in climate on weed growth and weed/crop competition, and secondary effects on crop hosts that may affect insect fecundity and pathogen success, will be evaluated.
- *Precipitation Change in Piñon-Juniper Ecosystems*. The southwestern United States is currently experiencing an extended drought, which has been blamed for widespread tree mortality. Although many coniferous species have been affected, the most extensive mortality has occurred to piñon pine (*Pinus edulis*), a species that

dominates one of the most extensive vegetation types in western North America, the piñon-juniper woodlands. Future climatic change is expected to exacerbate the frequency and severity of droughts in the southwestern United States. The first large-scale, replicated experimental study of the effects of changes in precipitation on a piñon-juniper ecosystem will be underway in FY 2007.

These activities will address Questions 8.1, 8.2, 8.3, and 9.2 of the CCSP Strategic Plan.



Aquatic Ecosystem Research. Aquatic ecosystem research priorities in FY 2007 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 using field work, observations, and ecosystem models:

- *Phytoplankton Carbon Biomass*. Global estimates of phytoplankton carbon biomass from remote-sensing data will be used to develop carbon/chlorophyll ratios in order to couple carbon and ecosystems models, and later to couple these with climate models. The comparison between observations and models helps improve the ecological models, therefore improving the ability to predict the responses of the ocean ecosystem and carbon stocks to global warming.
- *Salmon and Other Species Response to Climate Variability*. A collaborative research program will synthesize field and model information in the northeast Pacific to better understand and predict responses of these ecosystems to climate change. This synthesis will provide information for policymakers and decisionmakers about how salmon and other similar species respond to climate variability across the regions.
- *Coral Reefs*. Research addressing several potential climate-related threats to coral reefs will be advanced. A reef calcification index will be developed to provide an important bioindicator of overall reef health, and sustained monitoring will yield important insights into the impact of ocean acidification on these delicate systems. In addition, research will continue to develop a bleaching forecast system to provide managers and researchers with advance warning of impending thermal stress.
- *Coastal Wetlands*. The effects of elevated CO_2 on coastal wetlands and interactions with sea-level rise is very complex and not well understood. Experiments at a long-running marsh site using elevated CO_2 will be used to develop relationships between plant production, decomposition, and soil carbon and nitrogen. The studies will provide important information about how tidal wetlands respond to sea-level rise.

These activities will address Questions 8.1, 8.2, and 8.3 of the CCSP Strategic Plan.

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