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.

The terrestrial and aquatic ecosystems that make up the biosphere provide vital goods and services to humanity, including food, fiber, fuel, genetic resources, pharmaceuticals, cycling and purification of water and air, regulation of weather and climate, recreation, and natural beauty. Recent and ongoing global environmental changes—including climatic change, changes in atmospheric composition, land-use change, habitat fragmentation, pollution, and the spread of invasive species—are affecting the structure, composition, and functioning of many ecosystems, and therefore the goods and services that they provide. In turn, many ecological effects of global environmental change have potential to affect atmospheric composition, weather, and climate through both negative and positive feedback mechanisms. Because many global environmental changes are expected to increase in magnitude in the coming decades, the potential exists for increased effects of climate change on ecosystems and the goods and services that they provide (see Figure 16). Improved understanding of potential effects of global change on ecosystems, as well as the feedbacks from ecosystems to global change processes, remains a CCSP priority.

In FY 2009, the CCSP Ecosystems Interagency Working Group (EIWG) will continue with its planning, implementation, and analysis of research programs to accomplish the CCSP Strategic Plan goals related to ecosystem research. One focus will be increased efforts to provide the scientific basis needed for improved forecasts of the effects of climatic change on the structure, composition, and functioning of terrestrial and aquatic ecosystems, including the many goods and services that they provide. EIWG will also continue its FY 2007 and FY 2008 focus on the interplay between changing climate and the productivity and biodiversity of ecosystems, with an emphasis on improving understanding of ecological processes to accelerate model development and analysis. This research will include funding for two topics of particular urgency: (1) vulnerability of coastal ecosystems (both terrestrial and aquatic) to oceanic warming, sea-level rise, increased storm frequency or intensity, saltwater intrusion, and increased sedimentation and runoff; and (2) warming-induced changes in high-latitude and high-elevation ecosystems, including changes in primary production, species composition, the timing of water availability, and migration of the tree line and other ecotones. These topics require additional research on underlying ecological processes and responses and the development of models linking geophysical and ecological phenomena. Strategies for implementation include new *in situ* experimental research projects; observations of ecosystems at local, regional, and global scales; synthesis and analysis of diverse ecological data sets, including those from manipulative experiments; and ecological model development and evaluation.

EIWG efforts contribute to all five CCSP goals, with an emphasis on Goal 4: to "understand the sensitivity and adaptability of different natural and managed ecosystems…to climate and related global changes." EIWG activities directly address questions 8.1, 8.2, and 8.3 from the CCSP Strategic Plan. Synergies and interactions exist with all the other CCSP research elements (i.e., Atmospheric Composition, Climate Variability and Change, Global Carbon Cycle, Global Water Cycle, Land-Use and Land-Cover Change, and Human Contributions and Responses).

The agencies participating in the EIWG work collaboratively to plan and execute research described in the CCSP Strategic Plan. Many of the research accomplishments and plans described in this chapter are the outcome of multi-agency efforts. A number of these activities also involve collaborations between the agencies and non-Federal partners and cooperators. EIWG actively engages the larger scientific research community to obtain input to and feedback on its evolving research plans.

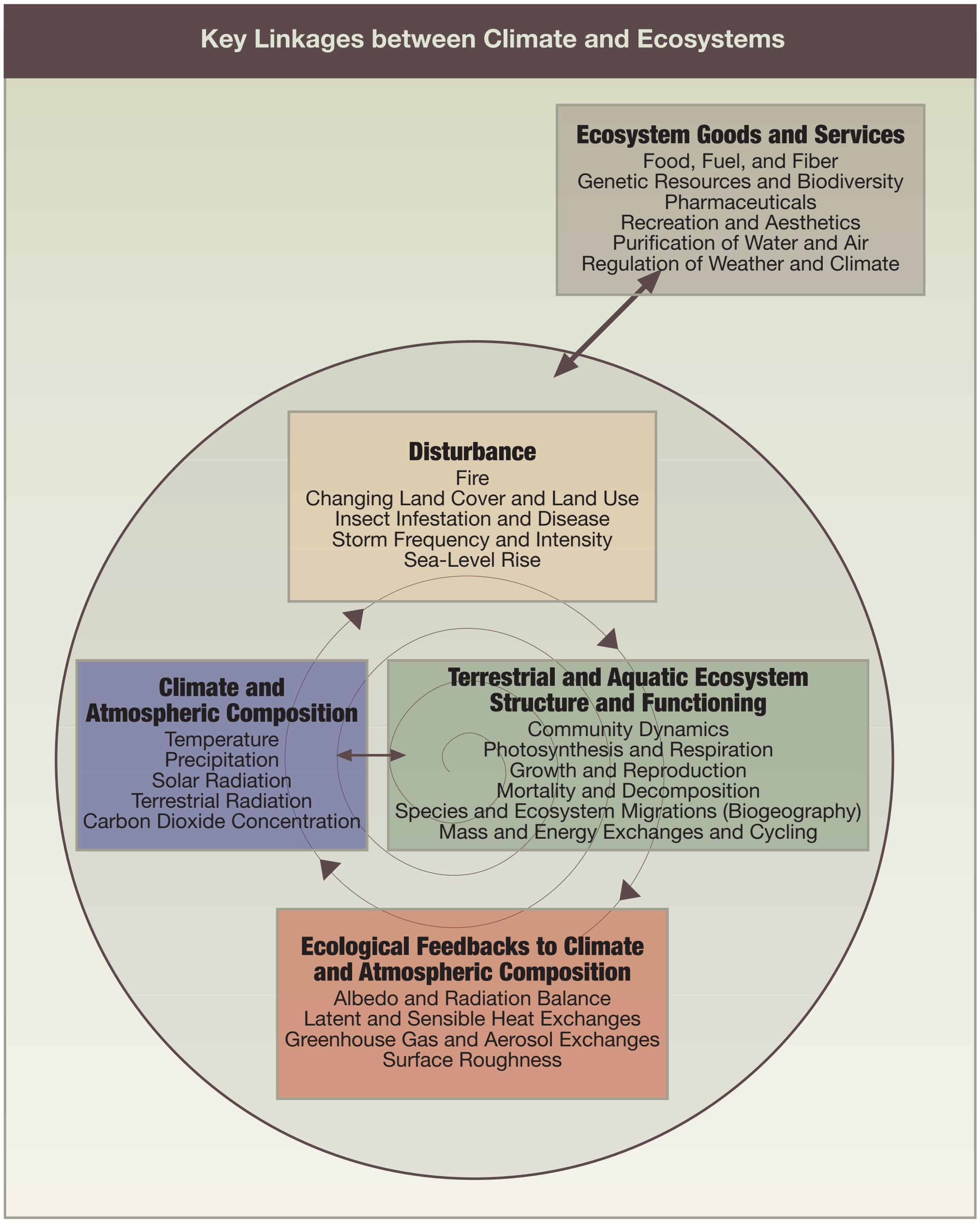


Figure 16: Key Linkages between Climate and Ecosystems. Climate changes (i.e., changes in temperature, precipitation, CO_2 concentration, wind, or solar or terrestrial radiation) can affect terrestrial and aquatic ecosystems by altering primary production processes, reproduction, health and mortality of organisms, and rates and pathways of decomposition, community dynamics and biogeography, and exchanges of mass and energy between ecosystems and the atmosphere. Climate changes also have the potential to affect the frequency and magnitude of various ecosystem disturbances (e.g., fire, disease, insect infestations, storm frequency, and land-use change). In turn, changes in ecosystem-atmosphere exchanges of radiation, heat, or greenhouse gases caused directly or indirectly by climate change have the potential to dampen or enhance the initial climatic change through negative or positive feedbacks. Ecosystem changes caused by climatic changes can also affect the many ecosystem goods and services on which society depends. Likewise, climate change effects on ecosystem goods and services may elicit human actions that in turn affect climate, ecosystem disturbance, and/or ecosystem structure and functioning. Temporal and spatial scales are implicit; temporal scales range from seconds to millennia and spatial scales range from local to global. *Credit: CCSP Ecosystems Interagency Working Group*.

Highlights of Recent Research

Climate Interactions with Tree Mortality and Regeneration are Complex.[1,2] Recent research is improving understanding of the complex interactions that can determine the effect of changing climate on vegetation mortality and regeneration. In the southern Appalachians, factors favoring seedling regeneration of particular tree species include warmer spring temperatures and dryer soil conditions, reduction of pathogen attacks on seeds in dryer soils, and warmer average temperatures. A synthesis of recent research indicates that with current climate trends, only higher elevation forests in this region are in danger of extinction. Changes in snowpack might be an important factor in other regions. Yellow cedar has been mysteriously dying in Alaska for over a century. After 20 years of study, researchers now hypothesize that this trend primarily results from decreasing snowpack, which increases soil freezing, kills vulnerable roots, and leads to foliar mortality and death. Recent tests of seedling survival in artificial snowpacks also support this mechanism as a factor in declining regeneration.

Soil Responses to Environmental Change.[3,4,5] Experimental warming of tundra indicated that ecosystem respiration increases most in dry tundra; that saturated soils dampen responses in wetter tundra; and that both carbon gain and respiration respond to warming. A Florida scrub oak ecosystem exposed to elevated carbon dioxide (CO_2) showed the largest increase in plant growth reported to date, but a 25% decline in soil carbon offset half of this increase in carbon accumulation, indicating that models may overestimate the potential for ecosystems to slow atmospheric CO_2 increase by storing carbon in soils (see Figure 17). Finally, in a constructed old-field ecosystem in eastern Tennessee, soil respiration increased with elevated atmospheric CO_2 and decreased with reduced soil moisture, but responses to

Florida Scrub Experiment

Figure 17: Florida Scrub Experiment. A soil core from the Florida scrub experiment. *Credit: B. Hungate, Northern Arizona University*.

experimental warming varied. This complexity in responses indicates that models should include mechanistic representations of the effects of multiple global change factors on ecosystem processes.

Competitive Interaction of Trees Altered by Carbon Dioxide and Ozone.[6] Changes in atmospheric CO_2 and ozone (O_3) concentrations may alter competitive interactions between tree species. Results from a long-term (10-year) field study in northern Wisconsin indicate that rising atmospheric CO_2 or O_3 concentrations would give a competitive advantage to paper birch over trembling aspen. Birch was less sensitive than aspen to damage by O_3, and in mixed stands birch was more responsive to the positive effects of rising CO_2 than aspen. While earlier, shorter duration experiments found little influence of these two gases on forest succession, these new results indicate that rising concentrations of either CO_2 or O_3 could alter the species composition of mixed aspen-birch stands that now cover millions of acres in the north central and northeastern United States.

Changes in Habitat Suitability for Tree and Bird Species.[7,8] One of the first steps in projecting possible impacts of climate change on plant and animal distributions and developing adaptive approaches to forest management is understanding how the distribution of environmental conditions suitable for individual species is likely to change over time. A new Climate Change Atlas web site presents results of extensive modeling efforts that combine current environmental relationships and species distributions with global climate models to project changes in potential suitable habitat for 134 trees and 150 birds of eastern North America by the end of the century (see Figure 18). Each species was modeled individually to show current distribution and potential distribution of suitable habitat in the future according to regionalized outputs of models for two Intergovernmental Panel on Climate Change (IPCC) emission scenarios and three climate models.

Modeling Impacts of Changing Climate on Intertidal Species Distributions.[9] A rich historical data record makes the intertidal zone a model system for examining the effects of climate change. Comparisons of historical and 2006 geographic distributions of the arctic barnacle *Semibalanus* and the tropical sand-worm *Diopatra* show parallel northward shifts at rates of 15 to 50 km per decade since 1872. Using modeled climate data from weather reanalyses, which provide the large-scale environmental envelope in which organisms existed over time, and simulation models of animal body temperatures, which allow simulation of organism response to the environment, researchers accurately modeled changes in the distributions of the two species over the past 50 years. Parallel shifts in distribution indicate that similar responses to a warming climate control the geographic limits of both species.

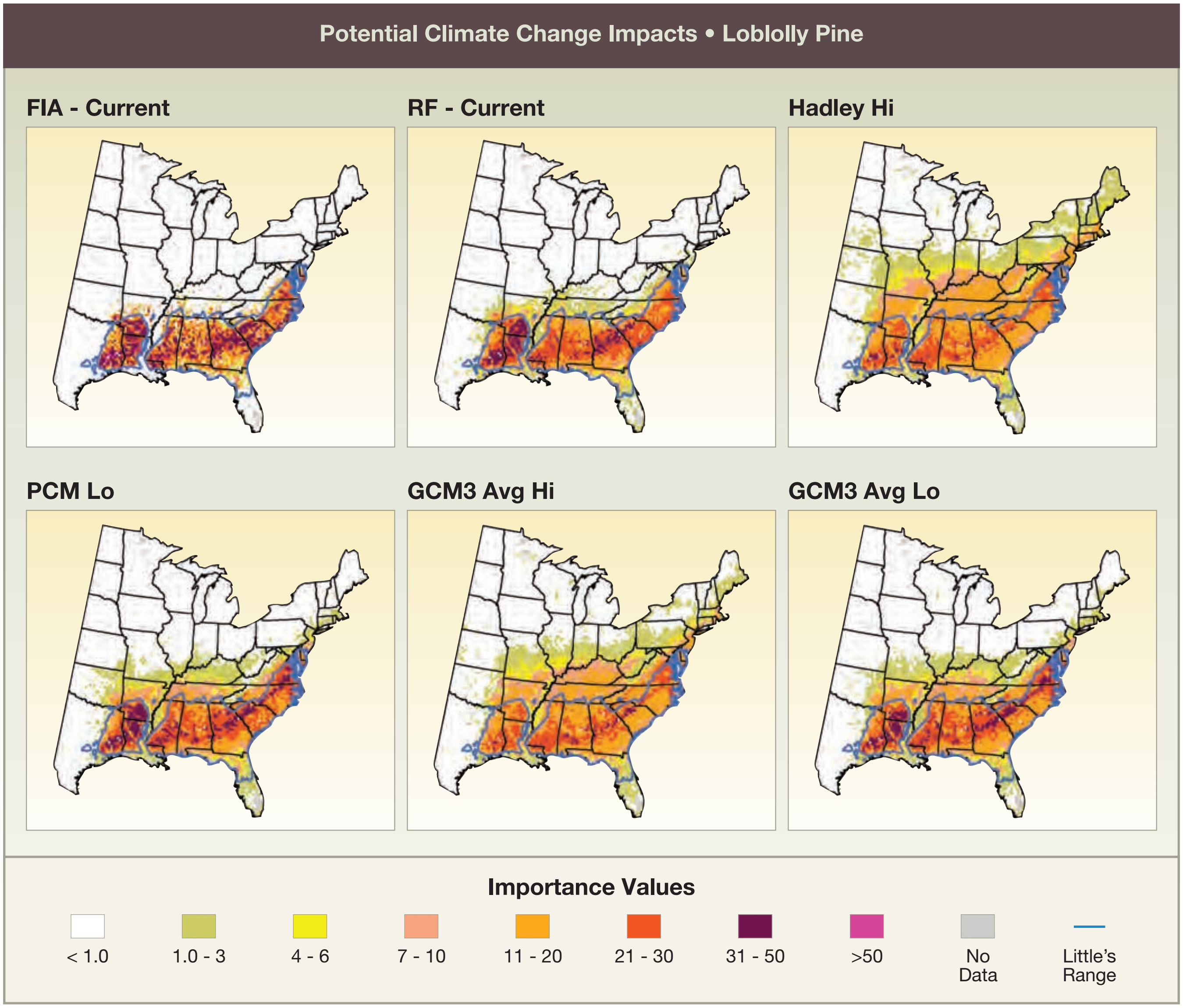
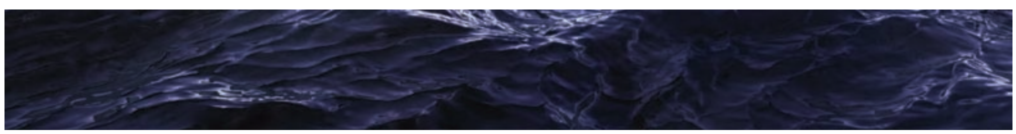


Figure 18: Potential Climate Change Impacts • Loblolly Pine. An example summary output from the Climate Change Tree Atlas (<nrs.fs.fed.us/atlas>) illustrates the potential impacts of changing climate on habitat suitability for loblolly pine under different climate change scenarios relative to current mapped (upper left) and modeled (upper center) distributions. The remaining four panels illustrate average projections from two general circulation models [Hadley CM3, DOE Parallel Climate Model (PCM)] as well as average projections (GCM3 Avg) from three models (Hadley, PCM, and Geophysical Fluid Dynamics models) under high- and low-emission scenarios. *Credit: Adapted from A.M.Prasad, L.R. Iverson, S. Matthews, and M. Peters, USDA Forest Service*.

Climate Impacts on Zooplankton Composition and Fish Feeding Preferences.[10] A series of studies on the Pribilof Island ecosystem in the eastern Bering Sea investigated why this area is able to support a large biomass of top predators, and whether the mechanisms responsible for production are sensitive to climate variability. One of these studies documented differences in the zooplankton community and the food ingested by juvenile walleye pollock on the Bering Sea shelf and in the Pribilof ecosystem for relatively cold and warm climate conditions. During the warm year, there were significantly fewer large, lipid-rich zooplankton prey for the juvenile fish than during the cool year.

Climate and Marine Fisheries—Spatial and Temporal Variability.[11,12] Understanding variation in time and space is critical to evaluating impacts of ocean changes on marine resources. Information from marked hatchery salmon has revealed local covariability in survival between adjacent coho stocks within a region of the Pacific Ocean and coherence in survival in adjacent regions, but no clear evidence of covariability at greater spatial scales. Other research suggests that Labrador Sea seawater from melting of the Greenland Ice Sheet is causing freshening of surface waters in the Gulf of Maine and Georges Bank. This fresher water flows southwest along the coast, keeping plankton near the surface under better growing conditions. Researchers expect higher plankton concentrations to provide more food for fish larvae, with higher survival and recruitment of adult cod and haddock stocks on Georges Bank.



California Current: Disruptions in Seasonal Cycles of Production.[13,14,15,16] California Current ecosystems are characterized by strong seasonal variability in productivity driven by the strength and duration of upwelling. Climate change scenarios suggest disruptions in phenology and biological interactions that depend upon seasonally predictable upwelling cycles. Recent observations support these expectations: A 4-year period of strong upwelling, cold ocean conditions, and high productivity from 1999 to 2002 was followed by 4 years of delayed or reduced upwelling, warm ocean conditions, and reduced productivity. In 2005, due to delayed upwelling, plankton biomass declined, seabirds failed to fledge young, and survival of salmon was very low. Should warm ocean conditions continue (as from 2003 to 2006), productivity in the California Current may decline.

Identifying Factors Contributing to Coral Reef Resilience.[17,18] Climate variability and change can negatively affect coral reef ecosystems (see Figure 19). Effective management needs to assess reef vulnerabilities, identify adaptive management strategies, and integrate these with existing decisions and mandates. Results from American Samoa show that adaptive management strategies could be implemented to increase reef resilience. A second study demonstrates how marine reserves contribute to resilience. Caribbean reefs became susceptible to changing from one stable state to another after a sea urchin (*Diadema antillarum*) die-off. Although the establishment of marine reserves increased

Partially Bleached Pacific Coral Reef

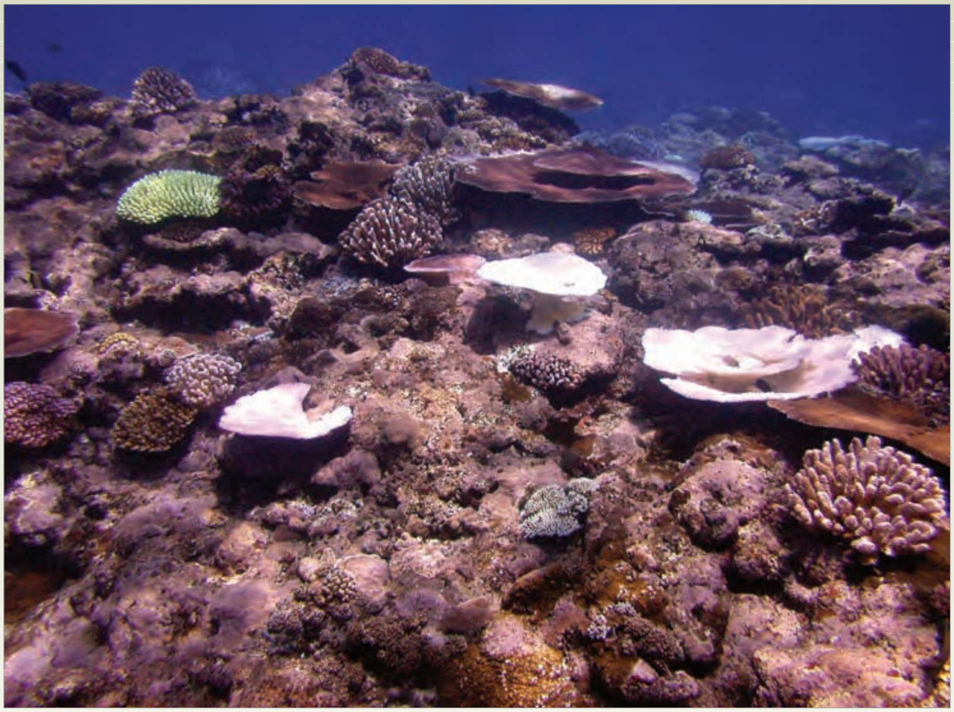


Figure 19: Partially Bleached Pacific Coral Reef. Coral reef species and communities vary in their resilience (ability to resist or recover) in the face of climate change impacts such as coral bleaching. *Credit: E. Mielbrecht, Emerald Coast Environmental Consulting*.

predation on parrotfishes, the current dominant species, protection from overfishing had a greater impact and ultimately allowed parrotfish densities to further increase. Increased grazing pressure from parrotfishes caused a fourfold reduction in cover of macroalgae, the principal competitors of corals.

Highlights of Plans for FY 2009

Establishing a National Phenological Network. Phenological data and models are important to agriculture, drought monitoring, and wildfire risk assessment, as well as management of invasive and pest species and infectious diseases. Existing phenological records are largely short term and spotty, however. In response, the U.S. National Phenological Network (NPN) is an emerging partnership among the academic community, several Federal agencies, and volunteers designed to fill that void through integration of data, analysis, and modeling. NPN will create four products: a meta-database of existing phenological data, a set of data collection and management protocols, lists of target species and infectious diseases representative of ecoregions, and an enhanced web site to facilitate communication and data access. While phenological models are important to infectious diseases and may be useful, few such models currently exist. Members of the public will be substantially involved as citizen-scientists in NPN.

This activity will address Questions 8.1 and 8.2 of the CCSP Strategic Plan.

Linking Arctic Climate Change, Societies, and Natural Systems. High-latitude ecosystems are experiencing the most pronounced environmental changes on Earth, making new research initiated as part of the fourth International Polar Year (IPY, 2007-2009) especially timely. Research will examine how key human services provided by natural ecosystems are changing throughout Alaska as the dynamic linkages between human social systems (both native and non-native) and natural systems change as warming continues to occur over time. Of particular focus in the study will be walrus, caribou, moose, wild berries, and forest fires.

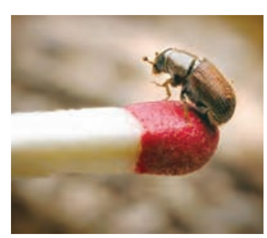
This activity will address Questions 8.1, 8.2, and 8.3 of the CCSP Strategic Plan.

Experimental Study of Warming at the Alpine Tree Line. Warming of several degrees Celsius, as projected for this century by climate models, has the potential to force the alpine tree line above the peak elevation of many western mountains of the United States. Such an upward "migration" of the alpine tree line might displace or eliminate existing alpine ecosystems (e.g., alpine meadows now found above the tree line). A set of experimental manipulations of temperature at the alpine tree line in the western United States is planned to begin in FY 2009. The experiments will determine effects of increased temperature on the ability of trees to germinate and grow at elevations above the present tree line, and thus to potentially displace existing alpine ecosystems if they experience future warming.

This activity will address Question 8.2 of the CCSP Strategic Plan.

Potential Impacts of Climate Change on Wildlife Habitats. Impacts of climate on vegetation are expected to significantly affect wildlife habitat and diversity. Wildlife agencies need information on these impacts as well as potential options for ameliorating them. Scientists will synthesize information on interactions between climate and vegetation change to quantify potential effects of predicted changes in habitat on terrestrial vertebrate biodiversity and identify management options.

This activity will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.



Tree Growth and Stand Dynamics Projections incorporating Climate Change. Scientists and managers will develop and evaluate approaches for integrating climate change into the Forest Vegetation Simulator. The simulator is widely used by forest planners and fire managers in the Forest Service, DOI, and other agencies to project effects on tree growth and stand-level

dynamics of thinning, prescribed fire, and other treatments, as well as effects of insect and disease interactions.

This activity will address Question 8.3 of the CCSP Strategic Plan.

Understanding Tropical Diversity with Satellite, Morphological, and Molecular Data. A combination of satellite remote sensing, measures of morphological traits from target bird species, and genetic markers is shedding light on the drivers of species diversification in the Ecuadorian Andes, a neotropical biodiversity hotspot. Morphological data allow detection of traits under selection and genetic techniques reveal the role of geographic barriers (e.g., mountains and rivers) in promoting divergent evolution. Remote-sensing data allow correlation of patterns of variation in the biological information obtained on the ground with climatic, topographical, and other environmental variables (e.g., vegetation characteristics) in order to elucidate some of the factors driving diversification. Correlating environmental landscapes with "morphological landscapes" and "genetic landscapes" will allow mapping of both biodiversity patterns and the underlying processes, vital information for projecting effects of climate change.

This activity will address Question 8.2 of the CCSP Strategic Plan.

Nonlinear Responses to Global Change in Aquatic Ecosystems. Several research efforts focus on identifying nonlinear responses to global change in aquatic ecosystems. Potential "regime shifts" involve the fundamental reorganization of natural ecosystems as environmental conditions change. They are difficult to predict, but may occur rapidly, and have potentially large consequences for ecosystem services. A new manipulative experiment will test predictions relating the stability of a Michigan lake to the structure of its food web. If predictions are correct, then it should become increasingly possible to forecast such changes in other ecosystems, perhaps in time to intervene. New modeling efforts will also contribute to the prediction of nonlinear responses. These results may be incorporated into local planning and management processes, to help prevent regime shifts in other aquatic ecosystems.

This activity will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Implications of Climate Change for Biological Indicators and Invasive Species. Research will be conducted on how biological indicators may be used to detect or control climate change effects in aquatic ecosystems, including changes in community composition, phenology, reproductive rate, evolutionary adaptations, and genetic selection. Assessment programs relying on biological indicators to document ecosystem condition will use this research to identify climate effects on ecosystems. This information allows modification of assessment programs to account for effects and to ensure that management goals continue to be met. Another indicator of potential changes is aquatic invasive species. Research will focus on implications of climate change effects on the invasion pathway and ecosystem management. A synthesis of management activities; effects on aquatic organisms, pathways, and ecosystem services; and available literature will describe adaptation options for aquatic invasive species management.

This activity will address Questions 8.2 and 8.3 of the CCSP Strategic Plan.

Impacts of Climate Change on Marine Fisheries. Regional ecosystem studies will be conducted to develop and test assessment and prediction capabilities to aid fisheries management. Monitoring and process studies will help determine the mechanisms and rates of climate impacts on ecosystems. Studies will also synthesize historical information on species of interest and collect new data necessary to construct models of their larval transport. The models will eventually simulate transport scenarios for regional changes in wind and runoff patterns, which drive the ocean currents. Reproductive success of many important fisheries species depends upon the transport of their eggs and larvae to suitable habitat. The development and testing of recruitment and environmental indices will also continue in order to increase their accuracy and precision for predicting important ecosystem changes.

This activity will address Question 8.2 of the CCSP Strategic Plan.

Ocean Acidification—Changing Oceans, Changing Ecosystems. Rising atmospheric CO_2 levels are altering ocean chemistry and threatening marine biodiversity. Decreasing oceanic pH resulting from increasing atmospheric CO_2 reduces the abilities of calcifying organisms, such as corals and crustaceans, to form skeletons and shells. It is increasingly urgent to have a mechanistic understanding of marine carbonate chemistry, including historical fluctuations and current trends, as well as predicting the responses of marine ecosystems to increased acidity (reduced pH). Upcoming research will include studies on historical fluctuations of pH based on the geological record, monitoring and establishing long-term time series of marine carbonate chemistry, *in situ* monitoring of calcification rates of key species, evolutionary change in organisms in response to changing chemistry, compensatory shifts in species within functional groups and the role of biodiversity in facilitating such shifts, effects of lower pH on coral calcification, functional genomics studies of pH effects on molecular regulation of calcification, and development of models to predict effects of multiple environmental changes on organism, population, and ecosystem-level adaptation.

This activity will address Question 8.2. of the CCSP Strategic Plan.

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