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?

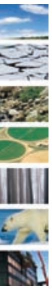
See Chapter 8 of the *Strategic Plan for the U.S. Climate Change Science Program* for detailed discussion of these research questions.

The terrestrial and marine ecosystems that make up the biosphere provide critical goods and services to humanity. These include food, fiber, fuel, genetic resources, pharmaceuticals, cycling and purification of water and air, regulation of weather and climate, and natural beauty. Recent and ongoing global environmental changes—including climatic change, changes in atmospheric composition, land-use change, habitat fragmentation, pollution, and spread of invasive species—are affecting the structure and functioning of some ecosystems, and therefore the goods and services that they provide. In turn, many ecological effects of global environmental change have the potential for feedbacks (either positive or negative) to climatic and other environmental changes. Furthermore, because many global environmental changes are expected to increase in magnitude in the coming decades, the potential exists for more significant effects on ecosystems and their goods and services. Reducing scientific uncertainties about the potential effects of global change on ecosystems, as well as the feedbacks from ecosystems to global change processes, remains a CCSP priority.

In FY 2008, the CCSP Ecosystems Interagency Working Group (EIWG) will continue with its planning, implementation, and analysis of research programs to vigorously accomplish the *CCSP Strategic Plan* goals related to ecosystem research. One focus will be increased efforts to provide the scientific basis for improved ecological forecasts of the effects of climatic change on the structure and functioning of terrestrial and marine ecosystems, including the many goods and services that these ecosystems provide. The EIWG will continue its FY 2007 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. These activities will include the funding of two topics of particular urgency: (1) the vulnerability of coastal ecosystems, both terrestrial and aquatic, to climate-related changes, including sea-level rise, increased sedimentation and runoff, increased storm frequency or intensity, saltwater intrusion, and oceanic warming; and (2) warming-induced changes in high-latitude and high-elevation ecosystems, including changes in species composition, alterations in the timing of water availability, and migration of the tree line. 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.

Efforts of the EIWG contribute to all five CCSP goals, with an emphasis on Goal 4 (to "understand the sensitivity and adaptability of different natural and managed ecosystems and human systems 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 other CCSP research elements, including, but not limited to, the Climate Variability and Change, Global Water Cycle, Global Carbon Cycle, and Land-Use/Land-Cover Change research elements.

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 joint efforts among multiple agencies. A number of these activities also involve collaborations between the agencies and non-Federal partners and cooperators. The EIWG actively engages the larger scientific research community to obtain input to, and feedback on, its evolving research plans.



Highlights of Recent Research

The following are selected highlights of recent ecosystems research supported by CCSP-participating agencies.

Quantifying Potential Ecosystem Feedbacks to Climatic Change.[1] Historical evidence shows that atmospheric greenhouse gas concentrations increase during periods of warming, implying a positive feedback from ecosystems to future climatic change. The feedbacks for carbon dioxide (CO_2) and methane (CH_4) were quantified by combining the mathematics of feedback with empirical ice core information and general circulation model (GCM) climatic sensitivity. It was found that the warming of 1.5 to 4.5°C associated with anthropogenic doubling of CO_2 in GCMs is amplified to 1.6 to 6.0°C warming. Indeed, there is growing experimental evidence that terrestrial ecosystems will amplify warming in the next century through changes in primary production, soil carbon storage, and CH_4 emissions due to changes in the length of growing seasons, changes in soil moisture, and reductions in permafrost. As a result, anthropogenic emissions that cause warming will result in higher final greenhouse gas concentrations, and therefore more warming, than would be predicted in the absence of these ecosystem feedbacks. Because key ecological feedbacks to climatic change are unrepresented in GCMs, and because asymmetrical uncertainty about those feedbacks favors higher temperatures, it is likely that the future will be warmer than implied by present GCMs.

Climate Impacts Fish Recruitment by Affecting Larval Transport.[2] Scientists have developed a tool to predict how climate and weather affect the transport of fish larvae to their nursery areas. Fisheries biologists and physical oceanographers constructed a numerical model to predict the larval transport of an economically important flatfish, northern rock sole (*Lepidopsetta polyxystra*), in the southeastern Bering Sea based on their vertical position in the water column. Sustained shoreward transport during the 1980s led to a decade of above-average recruitment, and along-shelf or offshore transport in the 1990s resulted in a decade of below-average recruitment. This new model can now be used with Intergovernmental Panel on Climate Change climate projections to investigate the effects of changing climate on larval fish transport and recruitment due to changes in currents and regional wind patterns.

Complex Responses of Subalpine Forests to Climatic Change.[3] Changing climates in the 21st century are anticipated to significantly alter subalpine forest distributions. Studies of medieval paleoclimates and forest distribution shifts in the high Sierra Nevada, California, are revealing potential influences of future climate change. Tree-ring analysis and wood anatomy of deadwood preserved above current treeline (>3,000 m) has documented the existence of a mixed-conifer forest growing from AD 815 to 1350 on mountain summits in the eastern Sierra where currently no forests occur (see Figure 11).

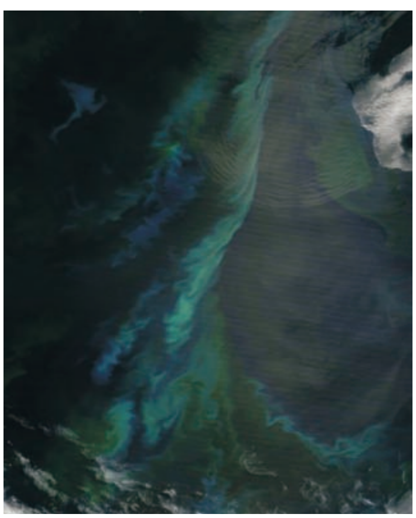
***Pinus lambertiana* Preserved from a Medieval Forest**

Figure 11: *Pinus lambertiana* Preserved from a Medieval Forest. Deadwood of sugar pine preserved from a medieval forest on Whitewing Mountain, eastern Sierra Nevada, California. The current range of this species is west of the Sierra crest (in background) and about 700-m lower in elevation. *Credit: C. Millar, USDA / Forest Service.*

The Medieval forest was composed of six species, including five whose current upper ranges are 200 to 500 m below the deadwood forest elevation in the eastern Sierra and one species that is now native only to the west slope of the Sierra Nevada at elevations more than 700 m below the deadwood location. Climates of the Medieval forest based on these data were significantly warmer (+3.2°C annual minimum temperature) and slightly drier (-24 mm annual precipitation) than present, values similar to those estimated for 2100 in the Sierra Nevada. The significant changes evidenced by the Medieval forest provide a case study of potential forest responses to be encountered in the future and indicate a much higher level of complexity than has been anticipated.

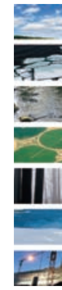
Climatic Synchronization of Periods of Prehistoric Widespread Forest Wildfires.[4] The ability of climate variation to synchronize widespread forest fires across much of western North America was recently documented for a multi-century period. During the past 400 years, the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) were the primary drivers of interannual to decadal variation in fire synchrony, whereas the Atlantic Multidecadal Oscillation (AMO) affected the strength of ENSO and PDO effects on wildfire synchrony at multidecadal scales. During certain phases of ENSO and PDO, fire was synchronous within broad subregions and sometimes asynchronous among those regions. In contrast, fires were most commonly synchronous across the West during warm phases of the AMO. The research is the first to demonstrate that synchrony in forest wildfires across western North America is directly related to surface conditions of the Atlantic Ocean. Current shifts to positive AMO conditions imply a potential for increased wildfire synchrony during the next few decades, in addition to that attributed to global warming.

Invasive Species Patterns Track Those of Native Species.[5] A review of patterns of species richness (the number of species in a given area) and species density (the mean number of species per square kilometer) for both native species and non-indigenous or invasive species of plants, birds, and fishes in the continental United States and Hawaii shows that the species densities of native and non-indigenous species are positively correlated for plants, birds, and fishes. The correlations of species densities between native and non-indigenous plants and native and non-indigenous birds are especially strong ($r = 0.86$ and 0.93, respectively). Densities of non-indigenous plant and bird species are also highly predictable with the densities of native plant species and native bird species being by far the strongest predictive variables. These results support the hypothesis that, at least for plant and bird species, "the rich get richer," in that areas with high densities of native species tend to be more susceptible to invasion by non-indigenous species. For plant and bird taxa in the continental United States, biodiversity itself does not appear to act as a barrier to species invasions.



Estimates of Tropical Pacific Ocean Productivity Lowered.[6] Ten field studies over the years 1994 to 2006 collected more than 140,000 *in situ* measurements of the chlorophyll fluorescence characteristics of phytoplankton in the surface mixed layer of the tropical Pacific Ocean. These measurements allowed the delineation of three major ecophysiological regimes in the tropical Pacific based on the factors constraining phytoplankton growth, hence the primary productivity, of these regions. Iron has a key role in regulating phytoplankton growth in both high-nitrate low-chlorophyll and oligotrophic waters near the equator and further south, whereas nitrogen and zooplankton grazing are the primary factors that regulate biomass production north of the equatorial regions. Application of these findings to the interpretation of existing chlorophyll information derived from satellites shows that productivity in the tropical Pacific basin may be 1.2 to 2.5 GtC yr^{-1} lower than previous estimates have suggested, a difference that is comparable to the global change in ocean production that accompanied the largest El Niño to La Niña transition on record.

Coral Reef Management Guide.[7] A workshop of scientists and managers, co-led by several CCSP agencies under the auspices of the U.S. Coral Reef Task Force, resulted in compilation of *A Reef Manager's Guide to Coral Bleaching*. The combined research results among state/territorial, Federal, academic, nongovernmental, and international scientists concluded that warming sea surface temperatures are a key factor in mass coral bleaching events. The *Guide* provides managers with strategies to support the natural resilience of coral reefs in the face of climate change.



Marine Pelagic Ecosystems: The West Antarctic Peninsula.[8] Penguins in the West Antarctic Peninsula are top consumers of marine resources, with diets of the most common species, the Adelie penguins, almost exclusively represented by one prey species, the Antarctic krill. The peninsula is experiencing some of the most rapid and significant warming on Earth, with two primary manifestations of change: the loss of sea ice and increased snow precipitation. One of the most striking responses is the change in penguin community composition during the last 3 decades, as ice-dependent and snow-intolerant Adelies have decreased while Chinstrap and Gentoo penguins have increased during a period of unprecedented environmental conditions (see Figure 12).

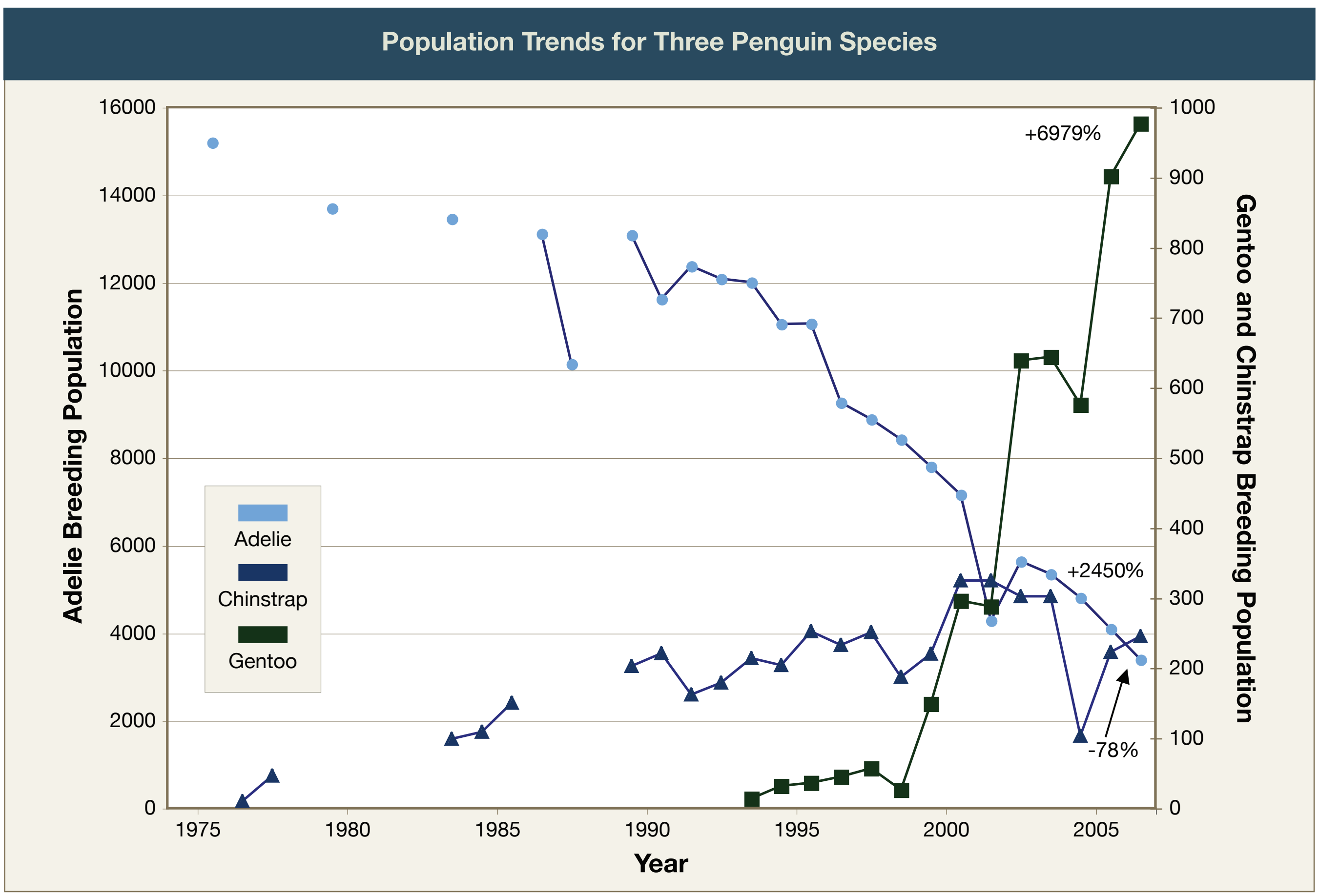
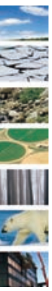


Figure 12: Population Trends for Three Penguin Species. Population trends for three penguin species in the Anvers Island vicinity, 1975 to 2006. The numbers on the graph indicate percentage change from initial sampling year for each species. *Credit: H. Ducklow, Marine Biological Laboratory; K. Baker and M. Vernet, University of California, San Diego; D.G. Martinson and S.E. Stammerjohn, Lamont-Doherty Earth Observatory; L.B. Quetin, R.M. Ross, and R.C. Smith, University of California, Santa Barbara; and W. Fraser, Polar Oceans Research Group (reproduced from* **Philosophical Transactions of the Royal Society B** *with permission from Royal Society Publishing).*

Nitrogen Limitation Constrains Sustainability of Ecosystem Response to CO_2.[9] Using free-air CO_2 enrichment technology in a prairie at the Cedar Creek Natural History Area in Minnesota, researchers in the BioCON (a long-term grassland project studying Biodiversity, CO_2 and N interactions) experiment found that some of Earth's plant life will not be able to sequester carbon from rising atmospheric CO_2 levels as well as scientists once thought. Instead, soil nutrients such as nitrogen will limit plant growth even when atmospheric CO_2 levels are higher. This study is the longest of its kind and consistent with other studies of trees and agricultural crops, providing evidence that nitrogen limitations may be common in the future in much of the world, despite widespread nitrogen pollution.



Highlights of Plans for FY 2008

CCSP will continue to gather and analyze information via experimental manipulation, measurement, modeling, and assessment studies to enhance understanding of ecosystems and of the processes affecting their changes. Key research plans for FY 2008 follow.

Effects of Changes in Precipitation on Southwestern Ecosystems. Climate models indicate that precipitation and soil moisture are likely to change in the southwestern United States during this century. To reduce scientific uncertainty about the potential effects of such changes on the structure and functioning of terrestrial ecosystems throughout the region, field experiments involving *in situ* manipulation of precipitation and soil moisture will be conducted in southwestern pinyon-juniper woodlands, coast sage, grassland, chaparral, and oak-pine forest ecosystems. Measurements will elucidate potential effects of altered precipitation on primary production processes, species diversity, decomposition of soil organic matter and related biogeochemistry, and aspects of ecological feedbacks to the physical climatic system.

This activity will address Questions 4.1, 5.4, 6.4, 7.5, 8.1, 8.2, and 9.2 of the CCSP Strategic Plan.

Improving Ecosystem Observations and Models. Current ecological, biogeochemical cycling, and climate models require more quantitative information on the variety, distribution, abundance, and temporal variability of terrestrial and marine groups of organisms having important physiological and ecological functions (e.g., key players in primary production, nitrogen fixers, invasive species). Planned activities for FY 2008 will focus on promoting abilities to detect attributes of these groups that can be derived through the analysis of continuous, high-resolution spectra spanning the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum. In addition, more realistic and robust ecosystem models need to incorporate additional major drivers of ecosystem processes, especially drivers in the human system through the incorporation of socioeconomic information. Doing so will improve the realism of (1) regional and global ecological models and (2) ecological component models that link to climate, hydrological, and/or atmospheric models.

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

Climate Impacts on Marine Ecosystems. Projects will be implemented to understand the responses of the physical environment and ecosystems to projected climate change scenarios and to develop predictions of the ecosystem impacts of these changes. These projects will collect observations, conduct research, and synthesize results to increase the understanding of regional climate impacts on marine ecosystems. This work will be conducted in conjunction with the development and refinement of biophysical indicators and models to provide living marine resource managers the knowledge and predictive tools necessary to adapt to the consequences of climate change for ecosystems.

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

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