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CLIMATE CHANGE AND ECOSYSTEMS

Thousands of scientists predict that the earth's climate will change because human activities are altering the chemical composition of the atmosphere through the buildup of greenhouse gases. The heat-trapping property of such gases as carbon dioxide, methane, nitrous oxide, and chloroflurocarbons is undisputed. Greenhouse gases are released into the atmosphere in large quantities by motorized vehicles, utilities, factories, appliances, and landfills.

Although there is uncertainty about exactly how and when the earth's climate will respond to higher concentrations of greenhouse gases, observations indicate that detectable changes are underway. Temperatures will most likely rise by an average of 2 to 6°F over the next century, along with measurable changes in precipitation, soil moisture, and sea level. All of these changes could have adverse effects on many ecological systems, as well as on human health and the economy.

WHAT CAN YOU DO?

- Inform yourself and other. To keep up with the latest scientific developments, check out EPA's climate change website at www.epa.gov/globalwarming. Or call EPA's National Service Center for Environmental Publications (NSCEP) at 1-800-490-9198 and ask for information on climate change.
- Encourage more research. If you work for an organization that carries out related scientific studies, suggest including a climate change component to the research.
- Reduce greenhouse gases. Use a more fuel-efficient (or non-motorized) mode of transportation. Carpool. Purchase electronic devices and appliances with the ENERGY STAR label. Plant trees.

EPA

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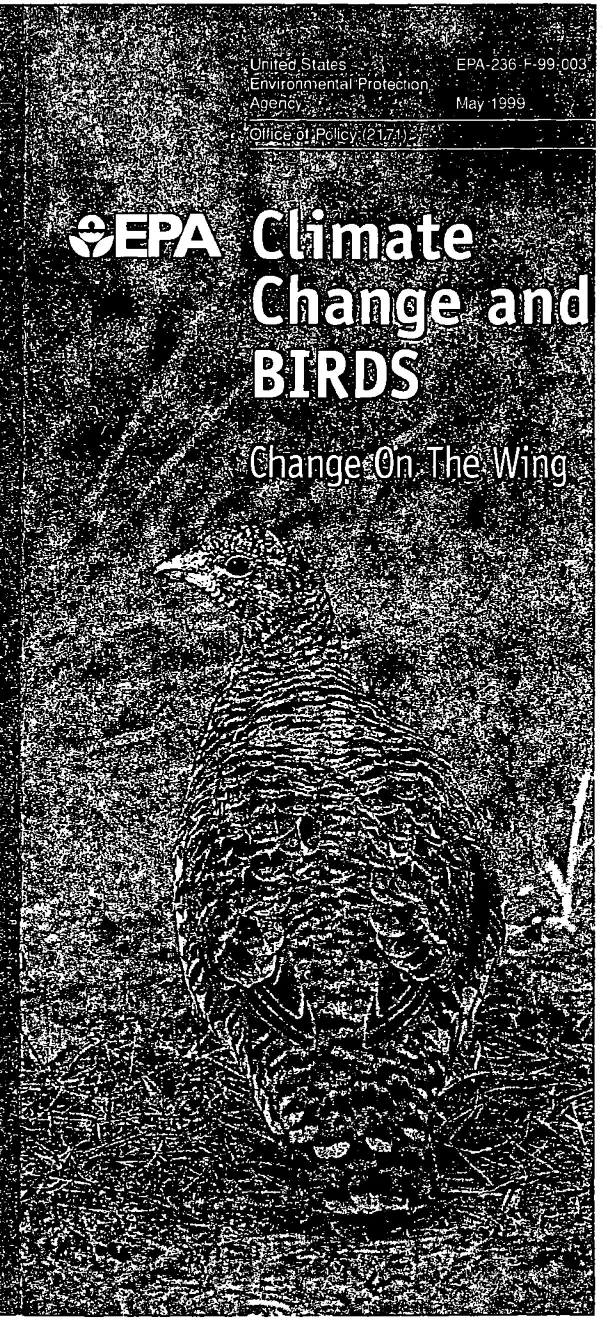

United States Environmental Protection Agency | EPA-236-F-99-003 | May 1999

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Climate Change and BIRDS

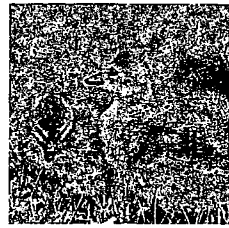
Change On The Wing

CLIMATE CHANGE AND BIRDS

Global warming could affect the abundance and distribution of birds in the United States. Changes in climate may change nesting and feeding habitats, migratory stopover areas, and the availability of key food sources. Some impacts may be positive, making conditions more favorable for certain kinds of birds. But climate change also could lead to reduced breeding success in some species and some localities, raising the possibility of regional population declines and extinctions.

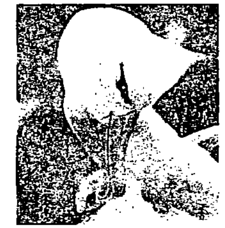
Birds require specific environmental conditions to survive and raise their young. Nesting, for example, is timed to coincide with favorable weather and food availability. If a trend toward warmer spring weather leads birds to nest earlier, their breeding success may suffer if primary food sources are not yet available when nestlings hatch.

Birds are more mobile than most other animals, and they simply can fly to a new location if a former site is no longer suitable. But global warming may make it difficult for some species to find new habitats. Plant and animal communities that provide optimal habitat today may be fundamentally altered in the future as the climate changes. A recent study suggests that ecological communities may not simply shift their range northward in response to warming, but instead may undergo complex changes as interacting species are affected in different ways by the changing climate.



CLIMATE CHANGE AND WATERFOWL

Changes in temperature and precipitation predicted under global warming could affect the nesting habitats of ducks and other waterfowl. According to one study, global warming could cause breeding populations of ducks in the north-central United States to decline by more than half—from 5 million birds today to between 2.1 and 2.7 million by the year 2060.



Why? Warmer temperatures and more frequent droughts could cause hundreds of thousands of ponds in the prairie pothole region of the north-central U.S. to dry up. The potholes account for only 10 percent of North America's waterfowl breeding habitat, but they produce 50 to 80 percent of the continent's ducks. The pothole region also serves as an important stopover point for migrating waterfowl. Although many of the affected ducks may move north into Canada, studies suggest that climate change may affect breeding habitats in Canadian prairies and forests as well.

AND SEABIRDS

Populations of sooty shearwaters off the coast of California and Washington declined by 90 percent between 1987 and 1994, a period when sea surface temperatures increased. The decline represents a potential loss of more than 4 million birds. The warmer water triggers a reduction in upwelling, a circulatory process that brings nutrient-rich water to the ocean's surface. Over the past two decades, reduced upwelling apparently has caused a 70 percent decrease in zooplankton, a key food source for shearwaters and the small fish that the shearwaters eat.

NATIONAL WILDLIFE FEDERATION®
People and Nature: Our Future Is in the Balance

Patricia Glick
Climate Change and Wildlife
Program Coordinator

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People and Nature: Our Future is in the Balance
Office of Federal and International Affairs
1400 Sixteenth Street, N.W. Suite 501
Washington, DC 20036-2266
Ph: (202) 797-6800

NATIONAL WILDLIFE FEDERATION
www.nwf.org

Dear Ms Ballentine,

Thank you for helping organize the meeting with DOI. I am very pleased that they are interested in working on climate change.

FYI, I have enclosed for you the same materials that I sent to Mr. Hayes, with the exception of "The Toll" report (since we had sent that to you a while back).

See you soon,

Patty

NATIONAL WILDLIFE FEDERATION®
People and Nature: Our Future Is in the Balance

Office of Federal and International Affairs

June 22, 2000

Mr. David J. Hayes
The Deputy Secretary of the Interior
U.S. Department of the Interior
1849 C Street, N.W.
Washington, D.C. 20240

Dear Mr. Hayes:

On behalf of the National Wildlife Federation (NWF), I would like to sincerely thank you for inviting us to participate in Monday's discussion about how we at NWF, and others in the environmental community, might work with the Department of the Interior (DOI) to educate the public about climate change and its potential impacts on the nation's wildlife and ecosystems.

As the scientific evidence increasingly shows, human-induced climate change poses a significant threat to America's parks and refuges, wildlife species, and natural resources. Therefore, strategies to address climate change must become an integral part of effective ecosystem management and protection. For example, DOI should contribute its scientific expertise by monitoring and studying climate change impacts on the lands, species, and natural systems the agency oversees. It should identify strategies to help wildlife become more resilient, and even adapt to, the effects of climate change. It should also integrate efforts to mitigate climate change into all long term management plans. Finally, with the enormous number of visitors that enjoy the nation's national parks and wildlife refuges, DOI should play an integral role in educating the public about how climate change might affect these treasures.

Bringing the issue of global climate change "home" to people, by showing them how it will affect the wildlife and wild places they know and love, is a critical step toward developing support for meaningful strategies to address the problem. This is the foundation of NWF's Climate Change & Wildlife Program. As an example of some of the work we have done over the past two years, I have enclosed for your review copies of recent reports, brochures, and articles in our magazines. We would be more than happy to share our experiences and ideas with you as you identify ways in which to incorporate climate change into your ongoing activities. Again, thank you for the opportunity to share our thoughts. We look forward to a continued dialogue with DOI on this important issue in the coming months. If you have any questions, please do not hesitate to call me at (202) 797-6898 or email glick@nwf.org.

Sincerely,

Patricia Glick

Patricia Glick
Coordinator, Climate Change & Wildlife Program

Enclosures

cc: Roger Ballentine

1400 16th Street, NW, Suite 501, Washington, D.C. 20036 Tel: 202-797-6800 Fax: 202-797-6646
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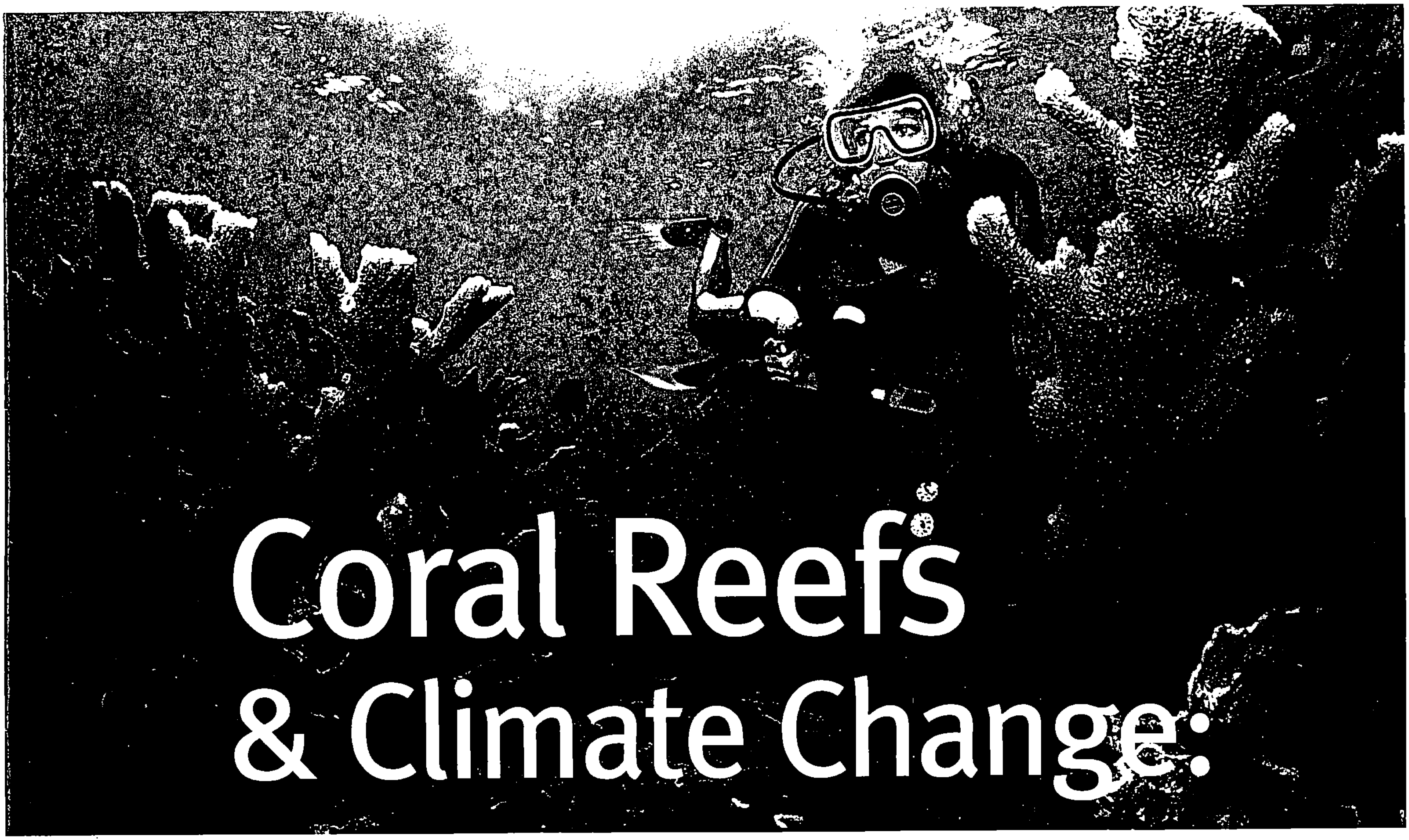

Coral Reefs & Climate Change:

Last Straw for a Threatened Ecosystem

By Patricia Glick
National Wildlife Federation's
Climate Change & Wildlife Program
October 1999

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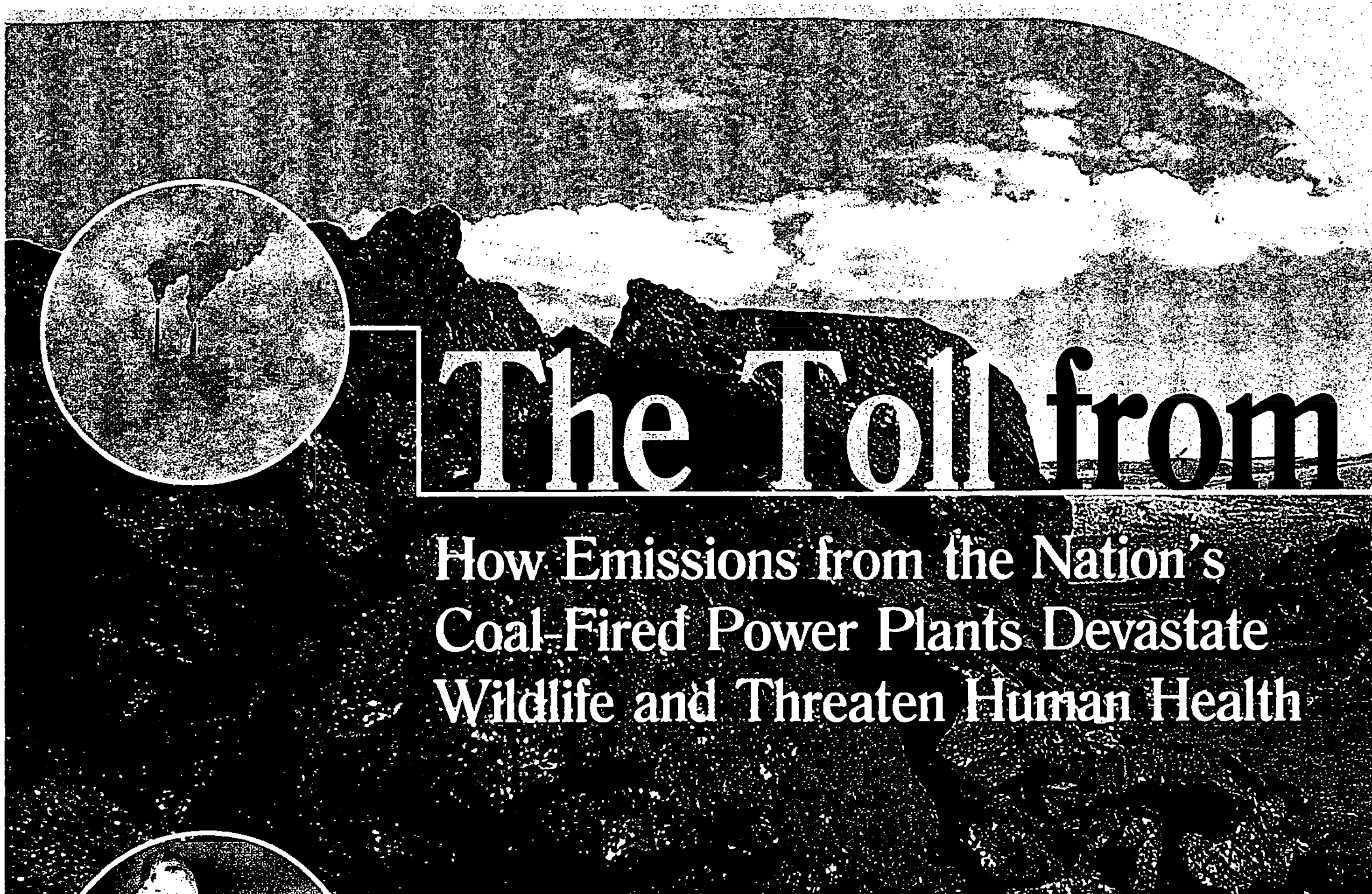

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The Toll from Coal:

How Emissions from the Nation's Coal-Fired Power Plants Devastate Wildlife and Threaten Human Health

The following North American species and ecosystems are particularly vulnerable to power plant pollution.

Studies have shown moderately high levels of mercury can cause serious reproductive problems for the American black duck, including high embryo and duckling mortality.

Lack of sufficient food sources (such as insects) due to acidification have also contributed to reductions in the number of black ducks throughout eastern Canada and the northeastern United States.

In addition, droughts and loss of wetlands due to climate change are expected to reduce major breeding habitat for most of North America's duck species, including the American black duck.

MERCURY
ACID RAIN
CLIMATE CHANGE

Common loons, particularly those in the Great Lakes and Northeast (where mercury contamination is the worst) face reduced fledging success as well as death as a result of mercury's toxic effects.

Loons are also susceptible to acid rain that reduces fish stocks (their primary food source) in lakes. On severely affected lakes, common loon chicks may die from starvation because of lack of suitable food.

MERCURY
ACID RAIN

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUL 6 1999

OFFICE OF
POLICY, PLANNING AND EVALUATION

MEMORANDUM

SUBJECT: Impacts of Climate Change on Wildlife

FROM: David Gardiner

TO: Roger Ballentine

Research on the ecological effects of climate change is returning compelling evidence that there is cause for concern about climate change impacts to wildlife. Scientists agree that studies reveal clear signals of potential climate-related effects. Despite this growing evidence, very little of the scientific research is making it into the public eye. We need: 1) to promote further scientific research in this area; and 2) to communicate more aggressively the results to lay audiences.

The most important messages to be communicated to the public are that: (1) the impacts of climate change on wildlife will be *local*; (2) ongoing research suggests that climate-related impacts are already being seen; (3) these changes are happening in places that we care about, and; (4) established ecological communities may be torn apart, resulting in unpredictable ecological surprises. For example, many of the birds we enjoy seeing in our backyards and parks will move northward and their populations may decline. Increased temperatures may cause a decline in the number of ducks settling to breed in the Prairie Pothole region, resulting in lost recreational opportunities for many Americans. With changes in ranges of bird populations, certain industries such as the timber industry may suffer increased economic losses due to greater damages from insect pests. No area is likely to remain untouched by climate change. Even our Refuges and National Parks that have been carefully set aside to protect wildlife and biodiversity will be affected by climate change. I have attached a short "Summary of the Science" that provides additional information on these impacts.

Possible Executive Actions

- Direct OSTP to increase emphasis of this issue in national and regional assessments.
- Direct funding for more research on the impacts of climate change on wildlife.
- Direct the Interior Department and other resources agencies to assess impacts on wildlife and habitat in national parks, national wildlife refuges and other public lands, and use agency resources to communicate risks to the public.
- Create research centers on wildlife and habitat or ecosystem impacts.

cooler water, or populations can shift northward if watersheds are connected. Stream and river fish can swim upstream toward cooler water in mountainous regions. However, habitat will be lost in some areas and freshwater fish are likely to be eradicated in specific areas of the country, especially at the southern boundaries of their ranges. Some of the most vulnerable cold water species such as trout may suffer complete elimination. Predicted increases in water temperature from climate change is also likely to eliminate most, if not all, suitable habitat for Pacific sockeye salmon.

Coral reefs

Coral reefs are dying at unprecedented rates due to bleaching, algal overgrowth, and coral disease. The amount of live coral cover at Carysfort (in a national marine sanctuary) has decreased by 62% from 1996 to 1998. Almost all monitoring stations (82%) in an EPA-sponsored network stretching from the Florida Keys to the Carolinas have diseased coral reefs. The increase in bleaching is related to temperature increases. A temperature rise of 1.5° C above the average summer sea temperature is too hot for most coral. Some models predict a rise of 1° C by 2020 for the Florida Keys area. Increased temperatures may also be one cause of increases in the number, duration, and extent of coral diseases. The best understood disease (black-band) is correlated with elevated nutrients, low salinity, and warm water temperatures.

Marine Mammals and Invertebrates

Since 1975, populations of chinstrap penguins on the western Antarctic Peninsula have increased while Adélie penguins have declined. The difference could be explained by changes in the extent of winter sea ice. Chinstraps and Adélies inhabit similar ranges but Adélie penguins spend the winter on the sea ice itself while chinstraps stay in the open water. In years of low sea ice, fewer Adélie penguins survive the winter, while chinstrap survival increases. Fifty years ago, heavy sea ice occurred in roughly four out of every five years. Today, it occurs in only one or two out of every five years.

Marine invertebrates are not free from the effects of climate change either. One study conducted at Hopkins Marine Station in Monterey Bay found that since 1930 and the present, most invertebrate populations with southerly geographic ranges have become more abundant, while those with more northerly ranges have declined. Those with wide geographic ranges are evenly split between increases and decreases in abundance. These effects correlate closely with increases in sea surface temperatures of 1°C in the region and climate change appears to be the most likely explanation for the phenomenon.

Attachment: Summary of the Science

Evidence suggests that many animals and plants have undergone shifts in distribution and the timing of life history events in recent decades and this shift is in line with what would be expected with a warming climate. Studies of distributions found northward shifts in the ranges of butterflies, birds, marine intertidal invertebrates, reptiles and amphibians in Europe and North America. Elevational shifts have been observed in butterflies in North America, birds in Costa Rica and alpine plants in Europe. Demographic studies have found ties between climatic conditions and declines of Sooty Shearwaters (sea birds) and shifting populations of Adelie and Chinstrap Penguins. Projected changes in temperature and precipitation will likely lead to increases in coral bleaching and mortality, with negative consequences for biodiversity, fisheries, tourism and shore protection.

Birds and Ducks

Climate change may be affecting the geographical ranges, migration patterns, and nesting habits of birds around the world. One study shows that spring arrival dates in the Upper Peninsula of Michigan between 1965 and 1994 were advanced by one to eight weeks for 15 bird species. Egg-laying dates of British birds were earlier by an average of 19 days in 1995 than they were in 1971. Other studies of North American and European birds confirm similar patterns of change.

Because of the change in life history events for birds, there is the possibility of unpredictable ecological surprises in the future. For example, birds perform a number of major ecological functions such as plant pollinators, seed dispersers, and controllers of insect-pests. Two of three species of warblers that specialize in feeding on spruce budworms have shifted their ranges northward by an average of 100 kilometers and are projected to shift further with more warming. The primary cause of lost timber production in Canada is the spruce budworm and with reductions in these birds, the timber industry could suffer much greater economic losses.

Some species of sea birds are also being affected by climate change. There is a documented 90 percent reduction in the population of sooty shearwaters over the last 25 years. About 5 million of these birds foraged in the California ocean current in the early 1970s. Their decline is correlated with an increase in sea surface temperatures and a coincident 80 percent decrease in the food available to shearwaters.

Climate change could also imperil key nesting habitats for North American waterfowl. About 50 to 80 percent of the continent's ducks breed in the Praire Pothole region. A temperature increase of 1.5°C is projected to lead to a greater frequency and severity of drought in the region, causing a 32 percent reduction in the number of ducks settling to breed. By 2050, ducks are projected to decline by 58 percent.

Fish

Freshwater fish are very sensitive to changes in water temperature and respond directly and strongly to climatic changes. When water temperature warms, lake fish can move downward to

- Explore cooperation with Canada in assessing impacts on migratory species.

Communications Opportunities

- Use National Wildlife Refuge Week in mid-October 1999 or the Refuge System birthday on March 14, 2000 to highlight impacts on shore birds. Refuge Week has increased the public's appreciation for the Refuge System: in 1996, over 150 refuge units staged Refuge Week events hosting 280,000 visitors. Two likely locations for an event would be any of the Delaware Bay refuges or San Francisco Bay National Wildlife Refuge. Climate impacts on ducks might also be highlighted at this time (e.g., state-by-state changes in duck populations with corresponding numbers on wildlife viewing and duck hunting in each state). Information on shorebirds will be available in late August or September. *Information on changes in duck populations in the US is already available. However, state-by-state information would have to be generated and would take several months to prepare.*
- Conduct state-by-state analysis of impacts on game birds for release before hunting season in the fall. Ducks Unlimited would be an interested partner in conducting such analyses. *Information on Upland Game Birds could be available about two weeks to one month after a request is made (Dr. Jeff Price would do this work); see comment above for availability of information on ducks.*
- Use National Fishing Week in mid-June 2000 to highlight effects of climate change on freshwater fish. State-by-state maps of fish presence and changes in ranges could be prepared showing changes at thousands of sampling stations across the country. Information on the popularity of fishing and expenditures on fishing by state could also be included in information sheets. *This information is readily available now but would require lead time of a few weeks to generate the maps.*
- Event or communication with Partners in Flight (400 organizations working for voluntary protection of birds). The big event for Partners in Flight is International Migratory Bird Day in May 2000. Participants in Partners In Flight include federal, state and local government agencies, philanthropic foundations, professional organizations, conservation groups, industry, the academic community, and private individuals. Their goal is to focus resources on the improvement of monitoring and inventory, research, management, and education programs involving birds and their habitats.
- Hold 2-3 small conferences with key researchers to summarize effects and publish summary - possible themes: impacts on ducks and fish and the projected effects on hunting and fishing opportunities, impacts on birds, impacts on plants and animals in national parks and wildlife refuges.
- Hunting Season - throughout fall (varies by state).
- Open direct dialogue with groups concerned about risks to wildlife, including Native Americans.

AN ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE IN THE NATIONAL PARKS, REFUGES AND PUBLIC LANDS IN THE UNITED STATES

A White Paper Prepared at the Request of the Vice-President of the United States

Prepared by

Department of the Interior

U.S. Geological Survey - Biological Resources Division
Tom Stohlgren, Dave Peterson, Stan Coloff, Dan Fagre
Virginia Burkett, and David Pyke

May 12, 1997
Rev. June, 1997

Climatic Change in the National Parks, Wildlife Refuges, and Other DOI Lands

Background

This document presents a brief overview of the lands and natural resources managed by the Department of the Interior (DOI) and of the human-induced stresses that impact these resources. With this as a framework, we overlay the predicted impacts of climate change on these lands and give some examples of resources vulnerable to these impacts. Given the current range of predictions regarding climatic changes, we conclude with some general implications for managing these public lands.

Although the magnitude and timing of potential climate change in parks, refuges, and other public lands is uncertain, generally accepted views on climate change effects at regional and global scales have been provided by The World Meteorological Organization/Intergovernmental Panel on Global Change (Watson et al. 1996). In brief, CO_2 levels have risen ~30% above pre-industrial (since 1860) levels, causing a mean surface temperature increase of 0.3-0.6 degrees C. With projected levels of increased emissions, global surface temperatures may rise 2 degrees C on average by 2100. The greatest changes in temperature are expected to occur in higher latitudes (Peterson and Johnson 1995, Keeling et al. 1996). Eustatic sea-level has risen 10-25 cm in the last 100 years, and will likely rise another 15-95 cm (mid-range 50 cm) by 2100 (Watson et al. 1996). Vegetation simulation models, such as the Mapped Atmospheric-Plant-Soil-System (MAPSS; Neilson 1993) biogeographic model, suggest that vegetation may change significantly through out the nation under a double-CO_2 scenario (Fig. 1).

The climate changes that may take place over the next 100 years are of the same magnitude as the changes which occurred over thousands of years during the Pleistocene Era (Watson et al. 1996). The climate that has helped shape the vegetation and wildlife and other characteristics of the DOI lands is expected to shift, while the boundaries of the natural protected areas (parks, refuges, wilderness areas and other DOI lands) remain fixed. Some of these areas may be changed such that they are no longer capable of providing the habitat or environment or other functions for which they were originally established. Also, some lands may change in such a way as to enhance economic benefits and human values. However, it appears the basic vulnerability of DOI lands under these climatic conditions may be characterized by species that fail to migrate, fail to adapt, migrate to a less-protected environment, or are otherwise placed at a competitive disadvantage.

Our ability to assess potential vulnerabilities of specific DOI lands to predicted changes has been hampered by: (1) poor resolution, bias, and uncertainty of general circulation models and global vegetation simulations; (2) poor understanding of two-way interactions between atmospheric and land surface processes at local and regional scales; and (3) insufficient information on landscape- and ecosystem-scale changes on plants, animals, and ecosystem processes. Despite these uncertainties, there is agreement that natural systems are more vulnerable to climate change than cultivated/urbanized ones primarily due to limited options for adaptation such as habitat fragmentation . (OTA 1993). Furthermore, patterns of response to climate change variables suggest that climate change may affect DOI lands and ecosystems through: sea-level rise and glacier retreat, altered disturbance frequency and intensity, accelerated spread of exotic species and diseases, accelerated habitat loss and loss of biodiversity, increased CO_2 and changes in the rates of ecosystem processes (how species function and interact with their environment).

1. Current Resources and Stressors

National parks, national wildlife refuges and other public lands managed by the DOI protect a wide range of landscapes and ecosystems including mountains, deserts, grasslands, coniferous forests, deciduous forests, floodplains, wetlands and coastal areas (Fig. 2). These lands contain natural resources, wilderness, wildlife, and recreational opportunities for America and the world.

Whereas some DOI lands function as large ecosystems, others are heavily influenced by human activities and multiple stresses. Over 80% of the total land area in the National Wildlife Refuge System, over 50% of the land area in the National Park System, and over 30% of the land managed by the Bureau of Land Management is located in Alaska. Most of the state of Alaska is comprised of federal lands dominated by pristine boreal forest, tundra and coastal ecosystems.

In the northern Great Lake States some of the more pristine areas still retain much of their pre-settlement character and serve as havens for wildlife and wilderness recreation (e.g., Isle Royale National Park, Seney National Wildlife Refuge). Other ecosystems in the eastern and southern U.S. are still recovering from extensive logging during the past century and some are developing into mature forests. Parks and refuges along the Atlantic coast (e.g., Assateague and Cape Hatteras National Seashores, Chincoteague and Cape May National Wildlife Refuges) protect valuable coastal resources such as highly productive estuaries, which serve as the breeding and feeding grounds for a wide range of marine life, including economically important fish and shellfish. In addition, the coastal barriers provide valuable habitat to many songbirds, sea turtles, and other wildlife. The barrier islands also protect the coastline of the eastern U.S. from the effects of storm surges and severe weather.

Cypress and bottomland hardwood forests on DOI lands are a critical interface between terrestrial and aquatic systems. Hurricanes threaten some areas of the Gulf and Atlantic Coasts nearly every year, and mangrove and some hardwood forests of southeastern national parks (Everglades, Biscayne and Virgin Islands) have not recovered from recent hurricanes which destroyed vegetation, wildlife habitat, and park facilities.

Stressors common to nearly all DOI lands include: increased development in and adjacent to federal lands, increased recreational use, altered disturbance and hydrologic regimes (natural fire, flooding), grazing by livestock or grazing by concentrations of protected wildlife, habitat fragmentation at landscape scales which is often intensified at boundaries, air pollution, and exotic species invasion. Most DOI lands are embedded in diverse mosaics of heavily modified areas (e.g., cities, towns, roads, and areas used for agriculture, grazing, or forestry). Most of the major rivers and streams in the US contain dams and reservoirs for water supplies, flood control, navigation and hydroelectric power. As a result, the reduced magnitude and frequency of floods has greatly impacted native riparian vegetation, facilitating the spread and persistence of exotic species (e.g., tamarisk and Russian olive trees, warm-water fishes; OTA 1993). Logging has converted most of the forestland outside of national parks in the lower 48 states to younger age classes, while agricultural practices and urban development have reduced functional wetland and riparian habitat. The existence of old-growth forests in Olympic National Park adjacent to thousands of acres of recent clearcuts clearly illustrates the vital role parks play in protecting natural systems from human impacts. More than 90% of California wetlands have been lost, making wildlife refuges and other protected areas critical for protecting migratory waterfowl and other species (USGS 1996). As urban areas encroach on wildlands, many forest ecosystems now have lower fire occurrence and increased fuel accumulation compared to the past few centuries due to fire exclusion.

Many ecological processes have been altered by land-use practices. For example, the Chesapeake Bay, the Nation's largest estuary, has experienced serious environmental degradation during the last century. The major environmental stresses in the region are from humans, linked to land use and highly populated urban areas. Coral reef ecosystems are threatened by nutrient enrichment from sewage and agriculture, over fishing, and stress from high sedimentation caused by deforestation, agriculture, vessel traffic, and coastal runoff (Jameson 1995). Over 40% of the plant species in Hawaii Volcano National Park are exotic species introduced by humans (Loope and Mueller-Dombois 1989).

Nearly all DOI ecosystems are impacted to some degree by exotic plants and animals, visitor use developments, and recreational impacts.

2. Additional Impacts Imposed by Climate Change and Selected Examples of Vulnerabilities

Climate change poses additional stresses to DOI and surrounding lands. Although there is considerable uncertainty in current predictions, particularly at the regional and landscape scales, evidence suggests that human-induced climate change will affect DOI ecosystems through: sea-level rise and glacier retreat, altered disturbance frequency and intensity, accelerated spread of exotic species and diseases, accelerated habitat loss and loss of biodiversity, and changes in the rates of ecosystem processes.

a. Sea-level Rise and Glacier Retreat

Direct climate change effects on DOI ecosystems are sea-level rise and the retreat (melting) of glaciers. Sea-level rise is caused by changes in precipitation, temperature rise, and the indirect effects of higher levels of atmospheric CO_2 (Ellison 1996). Field and modeling research on gulf coastal wetland systems, parks, and refuges from Texas to Florida show that sea-level rise has impacted the health, distribution, and loss of marsh and forest communities (Doyle 1997). Regional models predict that sea level rise, increased tidal range and saltwater intrusion over the next century will result in the landward encroachment of aquatic ecosystems: low lying hardwood and pine forest communities will be replaced by marsh habitat and significant acreage of marsh will be replaced by open water.

The change in distribution and abundance of coastal habitat on DOI lands will involve a loss of functional habitat for wildlife and recreation in some areas and the possible creation of new opportunities in other areas. For example, relative sea-level increases, associated with local subsidence, hydrologic alteration, sedimentation deficits and other factors, threaten productive wetlands in wildlife refuges (e.g., Sabine, Bayou Sauvage) of southern Louisiana, where coastal marshes are eroding at the rate of 70 km^2 per year (Figs. 3 and 4). Although not solely the result of eustatic sea-level rise, the submergence of the Louisiana coast provides and excellent physical model of how seal-level rise related to global change would impact other areas. Gulf coastal forests of Florida's Big Bend, Central, and Key regions composed of slash pine and cabbage palms have experienced diebacks in recent decades from saltwater encroachment of increased tides and surges (Ross et al. 1994, Perry and Williams 1996, Doyle 1997). Predicted changes in coastal habitat along Apalachee Bay in northwest Florida at St. Marks National Wildlife Refuge based on a land elevation model indicates a nominal loss/gain of marsh as a result of upslope migration and a net loss of coastal forest habitat in connection with the increase in sea-level (Doyle 1997). Simulations of south Florida landscape changes indicate that a complex of federal lands will undergo vast shoreline recession and habitat conversion that will reduce available land cover and habitat function under sea-level rise projections of 15-95 cm by the year 2100 (Doyle 1997).

Even a small increase in temperature will result in reduced areas of glacial ice, dramatically changing the nature of some alpine ecosystems. Long-term monitoring data from several Northwestern parks, including North Cascades National Park, which contains over half of the glaciers in the continental U.S., and Glacier National Park, show that glaciers have retreated significantly during the warmer climate of the twentieth century (Fig. 5) (Fagre 1997). One third of the earth's small non-polar glaciers occur around the Gulf of Alaska. Decline in these glaciers may affect sea-level rise, alter alpine ecosystems and contribute to downslope flooding.

b. Change in Disturbance Frequency and Intensity

Fire is an important component in many natural ecosystems. Fire suppression activities of the past 50-100 years (Ferry et al. 1995), has set the stage for extreme wildfires and rapid vegetation change during the next century. If fires are more common in the future, they initially could be larger and more intense, altering ecosystem structure and incurring increased costs for fire management and human safety. Patterns of succession may be atypical and species distributions may be less predictable given altered disturbance patterns, a rapidly changing climate, and competition from exotic species (see below). Insect and disease outbreaks may become more common in forests, killing more trees and further increasing the potential for wildfires. For example, fruit tree leaf roller infestations in southern baldcypress forests have become more common in forests that are stressed by subsidence in southern Louisiana (Goyer 1997). Repeated defoliation results in mortality of baldcypress saplings.

The greatest concern to southeastern coastal areas related to climate change is the prediction that storms will increase in intensity. Modeling studies suggest that increasing sea-surface temperatures increase the intensity of hurricanes (Emanual 1987). Recent examples in Everglades National Park, Florida and in the

Virgin Islands illustrate the effects of hurricanes on coastal systems. The possibility of long-term changes in large-scale atmospheric circulation (e.g., the El Nino Southern Oscillation) could result in more frequent high-intensity storms that would degrade the coastal barrier, leading to the loss of vulnerable estuarine areas and increased destruction of property and public facilities. A hindcast simulation of hurricanes from 1886-1989 indicated that the periodicity and trajectories of a few intense storms accounted for most of the impact on modern day mangrove forests across south Florida (Doyle and Girod 1997). When storms are very intense, vegetation and hydrological systems can be sufficiently modified to cause a permanent shift from forested intertidal (mangrove) ecosystems to barren intertidal or subtidal mudflats (Ellison 1996). Barrier islands that protect coastal ecosystems and urban areas will also become more degraded if storm intensity increases. The size of Louisiana's barrier islands has already decreased by 55% over the past century and a variety of methods have been used to slow the rate of erosion; increased storm frequency and intensity will accelerate this rate of land loss, exposing wetlands on DOI lands to storm damage (Williams et al. 1997).

c. Accelerated Spread of Exotic Species and Diseases

A long-term change in climate may shift the competitive balance among plant species, with a warmer climate encouraging the growth of more drought-tolerant conifers and weedy species. Exotic plants, for example warm season and cold season grasses, are becoming adapted to a wide range of habitats on most DOI lands. Aside from replacement of native plant species, some of the grasses, such as Johnson grass, are noxious weeds and toxic to livestock and wildlife. There is increasing concern that many of the species are becoming adapted to a wider range of habitats outside their native country. Increased temperatures, particularly warmer winter temperatures, are likely to expand the northern range of Chinese Tallow in the southern U.S. Currently, the distribution of this species is strongly limited by cold winter temperatures (Jones 1993). In addition, large inland bodies of water such as the Great Lakes, Lake Mead, Lake Powell, and the Salton Sea may have significant shifts in fish populations, with those species tolerant of warmer temperatures and more saline conditions better able to survive. Often these fishes are exotic species.

In the Intermountain West, where the Bureau of Land Management manages large tracts of public land, the invasion of exotic annual grasses threatens the integrity of many native shrub grassland ecosystems, which increases the frequency and intensity of wildfires. Along the Snake River in the Birds of Prey National Conservation Area, much of land has been converted from a native shrub grassland to an exotic annual grassland through a series of repeated wildfires (Fig. 6).

A rapidly changing climate may further aggravate the problem where the exotic annual grasses mature and dry out earlier than the native grasses and are thus more easily ignited and more susceptible to fire. The effect of increased CO_2 would likely change the competitive relationships of some range ecosystems in favor of some exotic grasses (Smith et al. 1987).

d. Accelerated Habitat Loss and Loss of Biodiversity

Competition for water between humans and natural systems is already high and may intensify with the added stress of accelerated climatic change. About 53% of the pre-settlement wetland area in the lower 48 states has been lost or converted to other uses (USGS 1996). Climate change is expected to accelerate the loss of wetlands and the biodiversity associated with them via the mechanisms discussed earlier (Watson et al. 1996). Wetland plant and animal communities along the shores of the Great Lakes (e.g., Indiana Dunes National Lakeshore, Ottawa National Wildlife Refuge) are closely related to groundwater hydrology, and will be altered if temperature increases and precipitation decreases. Wetlands on more-protected DOI lands will become increasingly important as refugia even as they are also altered and stressed by climate change. Coral reefs are extremely susceptible to additional stresses of climate change (including sea-level rise, increased sea-surface temperature and ultra-violet radiation effects) and their alteration is expected to greatly affect coastal fisheries and biodiversity (Watson et al. 1996). A recent change in the Northwest is a rapid increase in regeneration of forest communities at high elevations, thereby displacing meadows, altering wildlife habitat and potentially reducing recreational opportunities in popular parks such as Mt. Rainier (Fig. 7). The open forest areas of the forest-tundra ecotone in Rocky Mountain National Park are showing significant growth which is filling in canopy gaps and shading out tundra communities (Baker 1996).

e. Species Distribution Changes and Local Extinctions

The climate changes that may take place over the next 100 years are about the same magnitude as the changes in the Pleistocene Era, which occurred over thousands of years (Watson et al. 1996). Thus, similar changes in species distribution are predicted, and local extinction may occur for those species that fail to migrate, fail to adapt, migrate to a less-protected environment, or are otherwise placed at a competitive disadvantage. Changes in species' distributions are likely to be observed first at the limits of their current ranges (Stohlgren and Bachand 1997). For example, in a warmer climate, eastern white pine may become extinct at the southern limit of its distribution. In addition, increased stream temperatures, combined with higher atmospheric inputs of nitrogen, may alter the distribution and abundance of fish and other aquatic species in this region. Migration routes of caribou and waterfowl (e.g., in Denali and Gates of the Arctic National Parks and in Arctic National Wildlife Refuge) may be altered in response to habitat changes due to early snowmelt. Whales and seals may also shift their migration routes in response to ocean temperature changes and decreased extent of the Bering Sea ice. The distribution and abundance of salmon, which are sensitive to changes in water temperature, will almost certainly change in southern Alaska (Glacier Bay, Katmai, Lake Clark and Wrangell-St. Elias National Parks and Preserves) in a warmer climate with potential positive and negative effects on local fisheries. We know that bird species distributions are affected by their inherent abilities for temperature regulation and climatic adaptation (e.g., Martin 1997), but we do not know which species are most vulnerable upon emigration from more-protected DOI lands or habitats, to less-protected lands and habitats.

Because unique habitats are imperiled, rare and threatened species associated with them are also a major concern. Species endangerment patterns in the U.S. reflect highly fragmented landscapes and habitats (Fig. 8) (Flather et al. 1994). It is likely that climate change, land use change, and disruption of natural disturbance regimes will accelerate the local extinction of many species, but monitoring programs are few and predictive models at appropriate spatial scales are non-existent.

f. Changes in the Rate of Ecosystem Processes

A rapidly changing climate along with an increase in extreme weather events likely will affect ecosystem processes such as productivity, nutrient cycling, disturbance, herbivory, competition, and hydrologic processes. For example, a warmer, drier climate may result in less productive rangelands on millions of acres of land, thereby reducing their ecological and economic viability. In a drier climate, deep-rooted sagebrush will persist but not spread in grasslands; in a wetter climate, sagebrush will tend to replace grasslands, thereby reducing forage for cattle and some mammal and bird species. Lower soil moisture in some densely-stocked forests may produce sufficient stress to induce more frequent attacks by insect pests such as spruce budworm and fungal diseases in some species. Northern latitudes are predicted to have the greatest rates of temperature change (Watson et al. 1996). Some of the more northern forests, where organic matter tends to accumulate in soils, may produce an undesirable feedback where increased decomposition and altered nutrient cycling in a warmer climate results in a further increase in emissions of carbon dioxide to the atmosphere. Field experiments and observational studies are showing a change in the structure and composition of tundra plant communities in Alaska (Chapin et al. 1995).

Some potential effects of climate change (e.g. extended growing seasons, enhanced rates of plant growth) will alter the structure of federally protected ecosystems. For example, tree growth may be enhanced by increased temperature and atmospheric CO_2 at the forest-tundra ecotone in mountain parks. However, this may have negative effects for many understory plant and animal species that require open, patchy habitats, cover or light penetration through the canopy. (Chapin and Shaver 1996, Keeling et al. 1996).

3. Implications for Management

DOI land managers are confronted with the difficult challenge of maintaining natural populations and ecosystems with very limited information and a host of uncertainties that may not be resolved for many years. Based on the current state of knowledge, there are five basic strategies for addressing the effects of global change on natural ecosystems. Public education understanding and interpretation is common to each of these basic strategies.

a. Maintain or Restore Natural Disturbance Frequencies and Intensities

In forest ecosystems, it may be possible to modify fuel loadings with fuel treatments (e.g., prescribed burning) to reduce the intensity of future ignitions particularly in areas with the potential for large fires which may also present significant resource loss and ecosystem changes. Recent changes in USDA Forest Service and DOI fire management policy emphasize restoration of the natural role of fire in the ecosystem. This new policy will help resource managers address the difficult task of using fire as an ecological process in areas with differing land management objectives, and enable better preparation for fire-related impacts associated with extreme weather conditions and climate change. In dammed hydrologic systems, prescribed floods, like the one in the Grand Canyon in the early spring of 1996, should be used routinely to rejuvenate floodplains and aquatic and riparian habitats (Collier et al. 1997).

b. Enhance Migration Corridors and Use an Ecosystem Approach

If populations of sensitive plant and wildlife species limited to parks and refuges are displaced because of climate change, managers may seek to establish buffer zones and migration corridors (pathways that allow safe movement of species from one location to another) to continue to protect these sensitive resources to ensure long-term survival. Conflicts over natural resources among federal agencies, state agencies and local residents are already common and could become more common in the future if distributions of plants, wildlife and fish are altered. In many areas, it will be especially important to develop conservation strategies at large spatial scales that overcome or bypass barriers such as roads, cities, croplands, fragmented habitat, and other physical and biological obstacles. This means that federal agencies will need to cooperate increasingly with state and local governments and all other stakeholders and work to resolve these complex issues from a broad ecosystem perspective.

c. Increase Exotic Species Mitigation Efforts

The reestablishment of native species by improving the competitive advantage is a key approach to the mitigation of exotic species. Increased emphasis on developing biological controls and technologies which integrate biological, chemical and physical control technologies is needed. The selected application of fire is one important management tool that may be used effectively along with efforts to reduce the viability and spread of exotic species. Warmer stream temperatures, exacerbated by dams and water diversions, which can increase the competitive advantage of exotic fishes over native fishes, may be influenced by riparian vegetation that provides a protective cover from sunlight. Efforts to lessen disturbance, and nitrogen inputs, (including atmospheric deposition), should be considered to curb the establishment of exotic plants, particularly exotic grasses, which benefit from increased disturbance, and nitrogen inputs from air pollution. Mitigation efforts must be increased, and shifts from native to exotic species, and increases in native and exotic pathogens, must be carefully monitored.

d. Develop an Adaptive Management Philosophy

Despite the inherent uncertainties of climate change, land managers must view climate change as an additional stress to DOI and surrounding lands. Human activities have created ecological "islands" in a sea of contrasting land uses and management objectives. The public lands, which serve a wide range of public needs, also provide the setting for the study and practice of new adaptive ecosystem management concepts. Adaptive management is a management concept in which ecosystem responses to management actions are carefully monitored and evaluated and used to revise and direct future management approaches. These concepts are likely to provide the practical understanding for resource managers to be able to adapt and/or mitigate the impacts of future climatic change and other environmental stressors. For example, managing small tracts of lands (e.g., parks and refuges) for pre-settlement plant and animal communities may become increasingly difficult and impractical if temperature and precipitation changes force new plant and animal communities to be formed within these protected areas. Efforts should be made by federal agencies to increase the functionality and adaptability of their lands by working with other agencies and private landholders to protect habitat and wildlife on the boundaries of parks, wildlife refuges, and other DOI lands. Recent land acquisitions, conservation easements and water-allocation agreements associated with Everglades National Park are a good example of this approach.

e. Expand Natural Resource Inventory, Monitoring, and Research Activities

Successful natural resource management requires an integrated, science-based ecosystem inventory, monitoring, and research program. The DOI public lands, parks, refuges, and wilderness areas provide a wide range of natural laboratories well suited for studying the impacts of various stresses on ecosystems for testing and developing adaptive management strategies. Evaluating the biological and socio-economic effects of multiple stresses on DOI ecosystems demands a long-term commitment to interdisciplinary science. Within DOI lands, highly fragmented habitats (e.g., wetlands, tallgrass prairie), areas of high native diversity, sensitive habitats and those with distinct or endemic species assemblages deserve immediate attention. Rare and threatened native species also deserve special attention, especially in relation to altered disturbance regimes, climate change, and displacement by exotic species. Emerging climate change research programs in the DOI are using combinations of field observations, experimental manipulations, and predictive models to characterize ecosystem response to climate change and to develop management strategies for an uncertain future. The uncertainties associated with climate change present the Department with a significant challenge, and its greatest opportunity to preserve and protect some of America's most valued natural resources.

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Global Change and Department of the Interior Public Resources:

A Summary

Importance of DOI Lands

- Encompass large areas and wide range of landscapes and ecosystems throughout the United States and Territories

- Contain important natural resources used by the American public and vital to the economy through grazing, agriculture, mining, recreation, and tourism

- Protect unique and nearly pristine biological features, including rare species of plants, fish and wildlife, and unique ecosystems

Existing Stresses on Resources Exacerbated by Climate Change

- Increased development, and recreational and economic use demands

- Habitat fragmentation, especially in surrounding landscapes

- Air and water pollution

- Exotic species invasions

- Altered disturbance and hydrologic regimes

- Increased intensity of wildfire and other disturbances

Additional Potential Impacts of Climate Change

- Direct effects of sea-level rise on coastal DOI lands and melting of glaciers in mountain ecosystems

- Increased intensity and frequencies of disturbances such as fire, floods, droughts, and hurricanes

- Accelerated spread of exotic species and disease

- Accelerated habitat and biodiversity loss

- Changes to fundamental ecosystem processes

Management Implications

- Develop tools and policies for managing frequencies and intensities of disturbance
- Expand efforts to curtail and mitigate exotic species and diseases
- Emphasize ecosystem approaches and actively enhance corridors and linkages
- Develop Adaptive Management policies
- Expand biological inventory, monitoring and research

MAPSS Simulated Vegetation Distribution

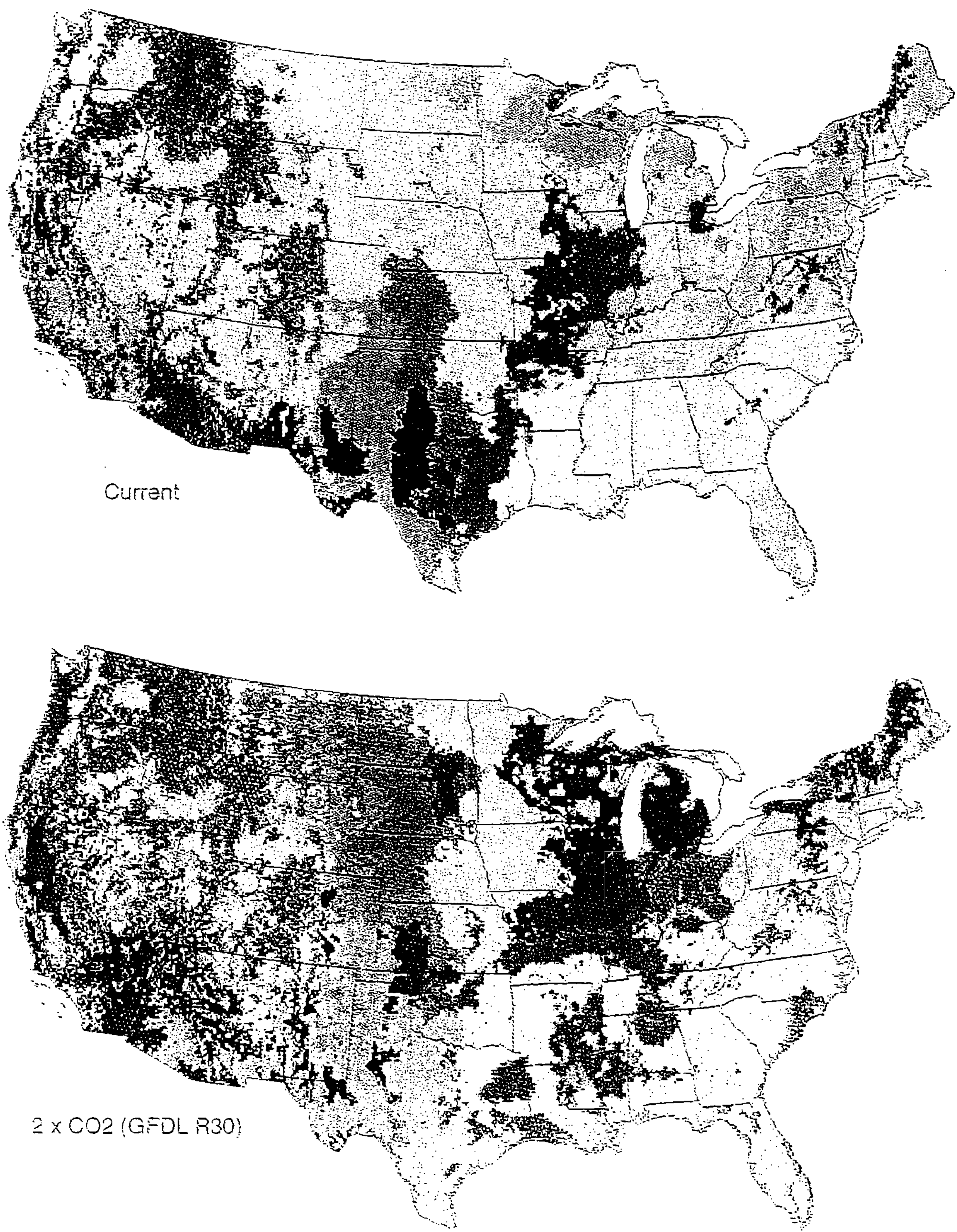
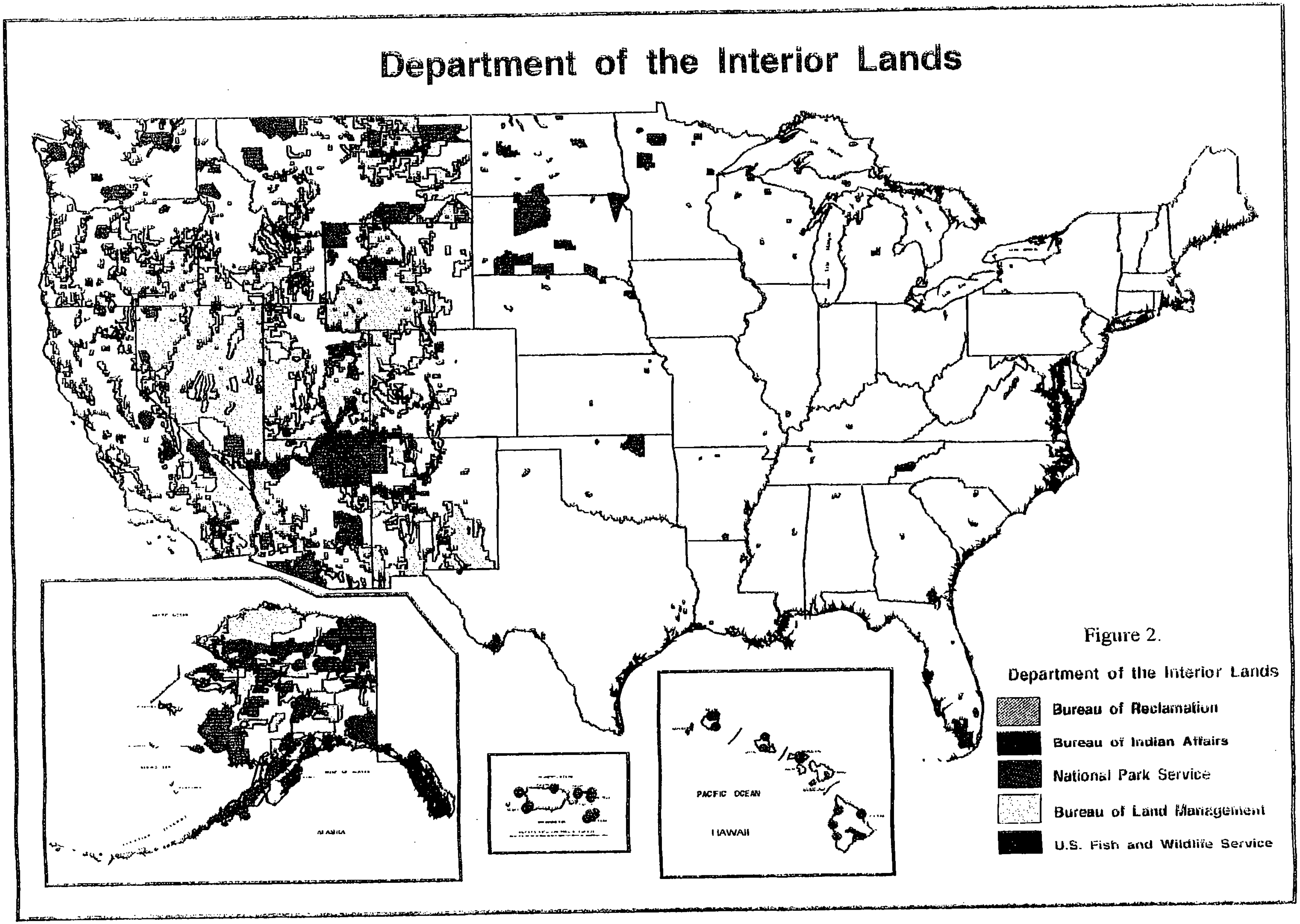


Figure 1. Distribution of different potential vegetation types within the United States as simulated by Mapped Atmospheric-Plant-Soil-System (MAPSS) biogeographic model. Note Changes in vegetation between current condition and a doubled-CO_2 climatic scenario. Ecosystems are predicted to change dramatically on most federal lands in the continental United States.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PACIFIC OCEAN
HAWAII
ALASKA
Department of the Interior Lands
Bureau of Reclamation
Bureau of Indian Affairs
National Park Service
Bureau of Land Management
U.S. Fish and Wildlife Service

Figure 2.

LAND LOSS IN THE LOUISIANA COASTAL ZONE 1955/56 - 1978

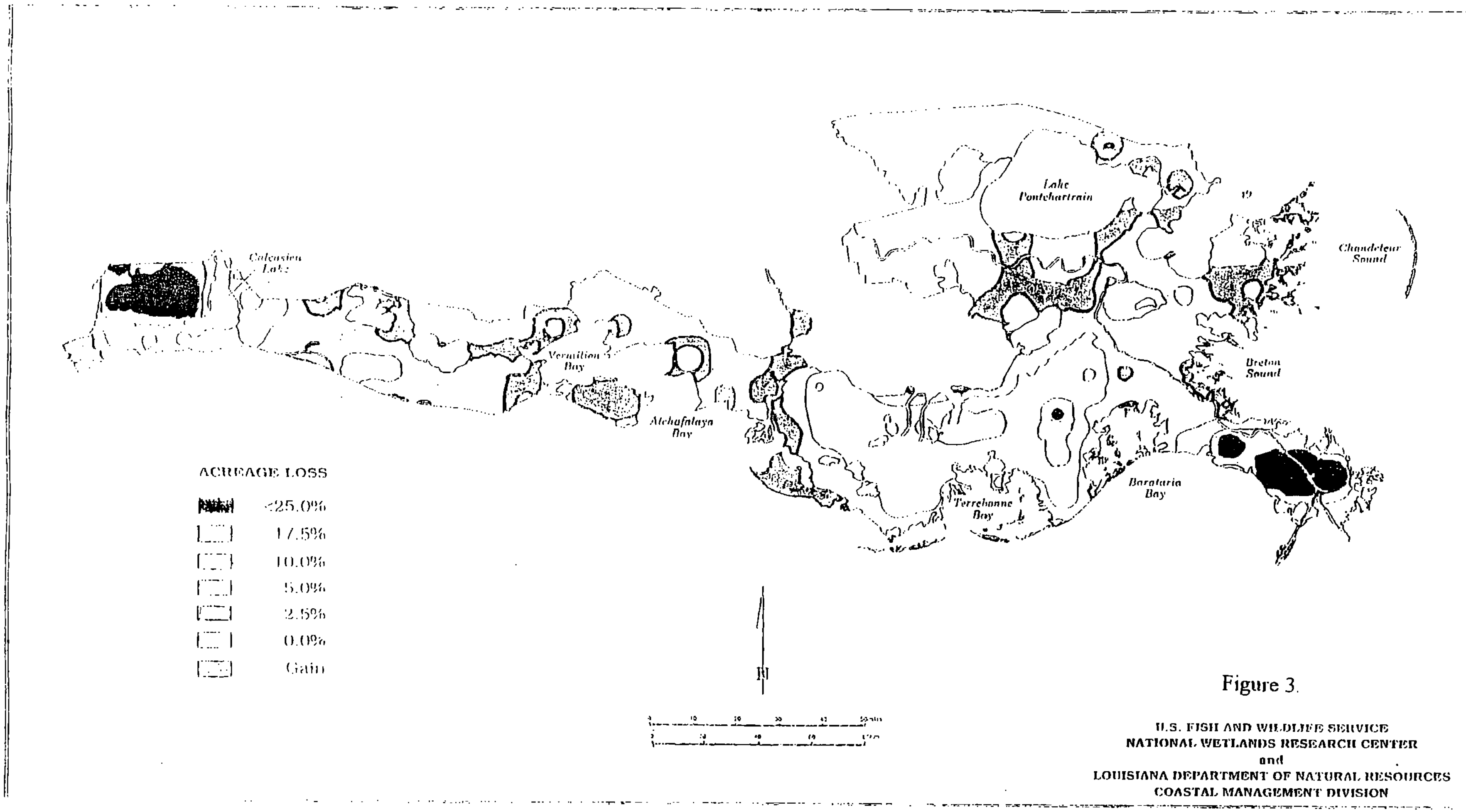


Figure 3.

U.S. FISH AND WILDLIFE SERVICE
NATIONAL WETLANDS RESEARCH CENTER
and
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
COASTAL MANAGEMENT DIVISION

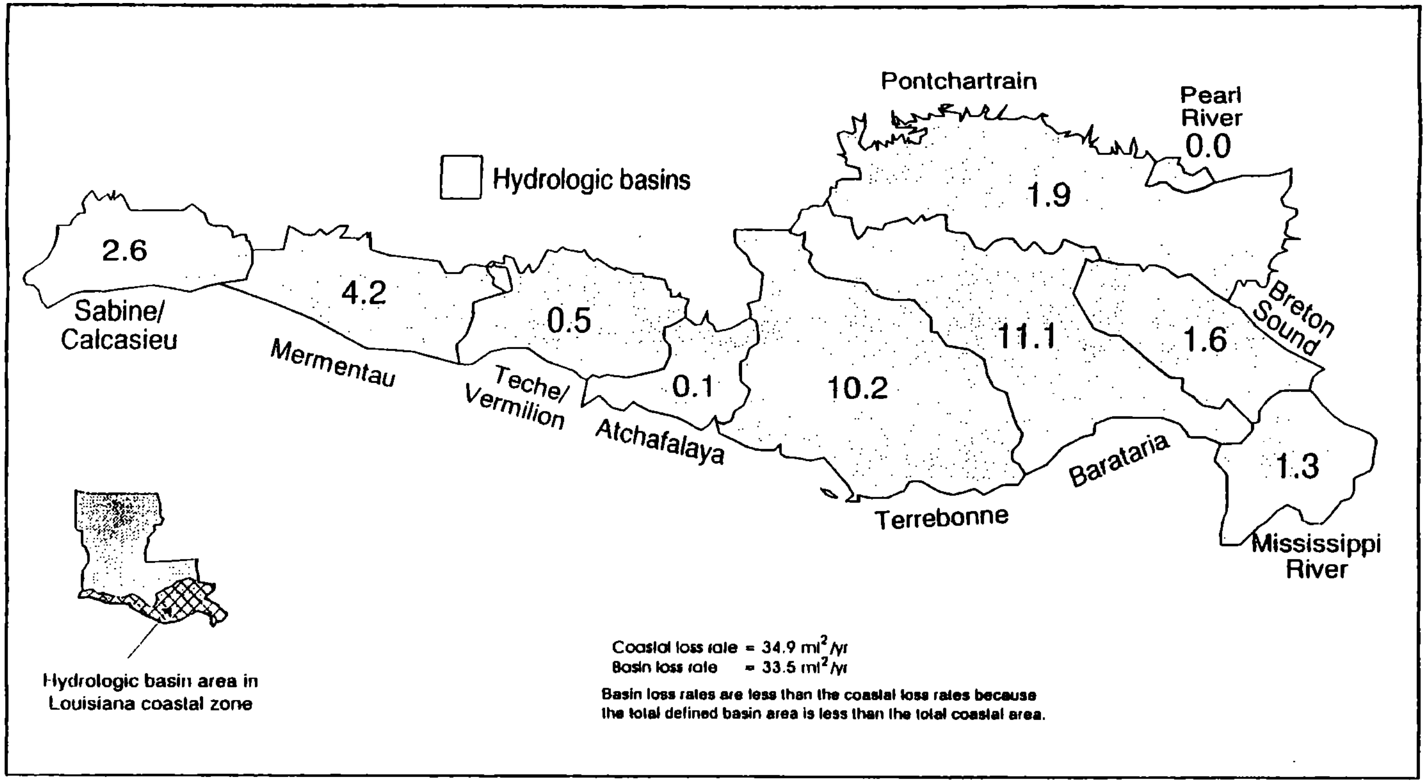


Figure 4. 1978-90 loss rates for coastal hydrologic basins (sq. mi/yr) and total coastal Louisiana.

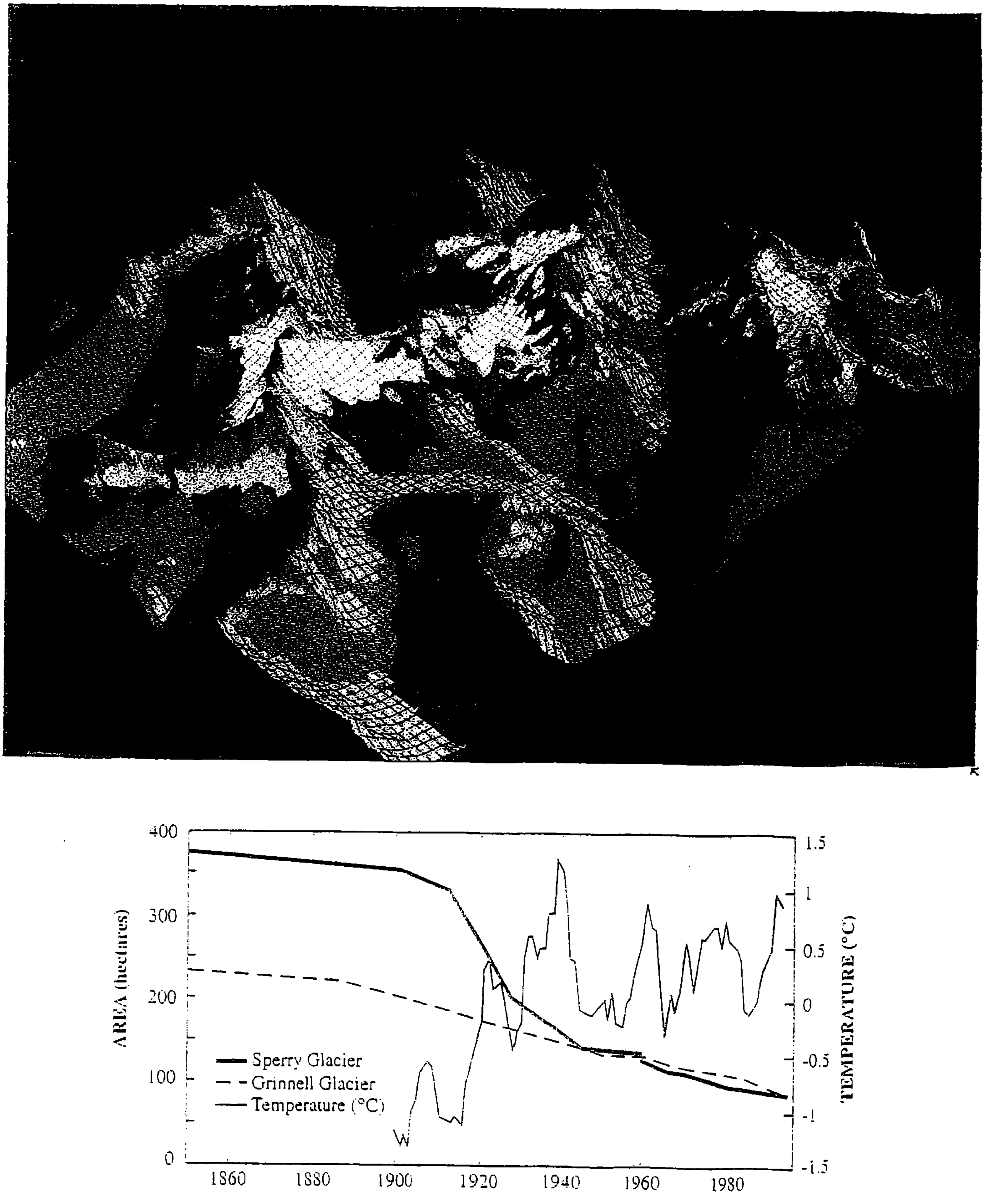


Figure 5. A geographic information system representation of glacier shrinkage from 1850 to 1993 in Glacier National Park. Yellow areas reflect current area of each glacier. Red and orange represent the previous extent of glaciers at various times in the past. Glacier area is strongly correlated with temperature, and further shrinkage could eliminate may alpine glaciers by 2030.

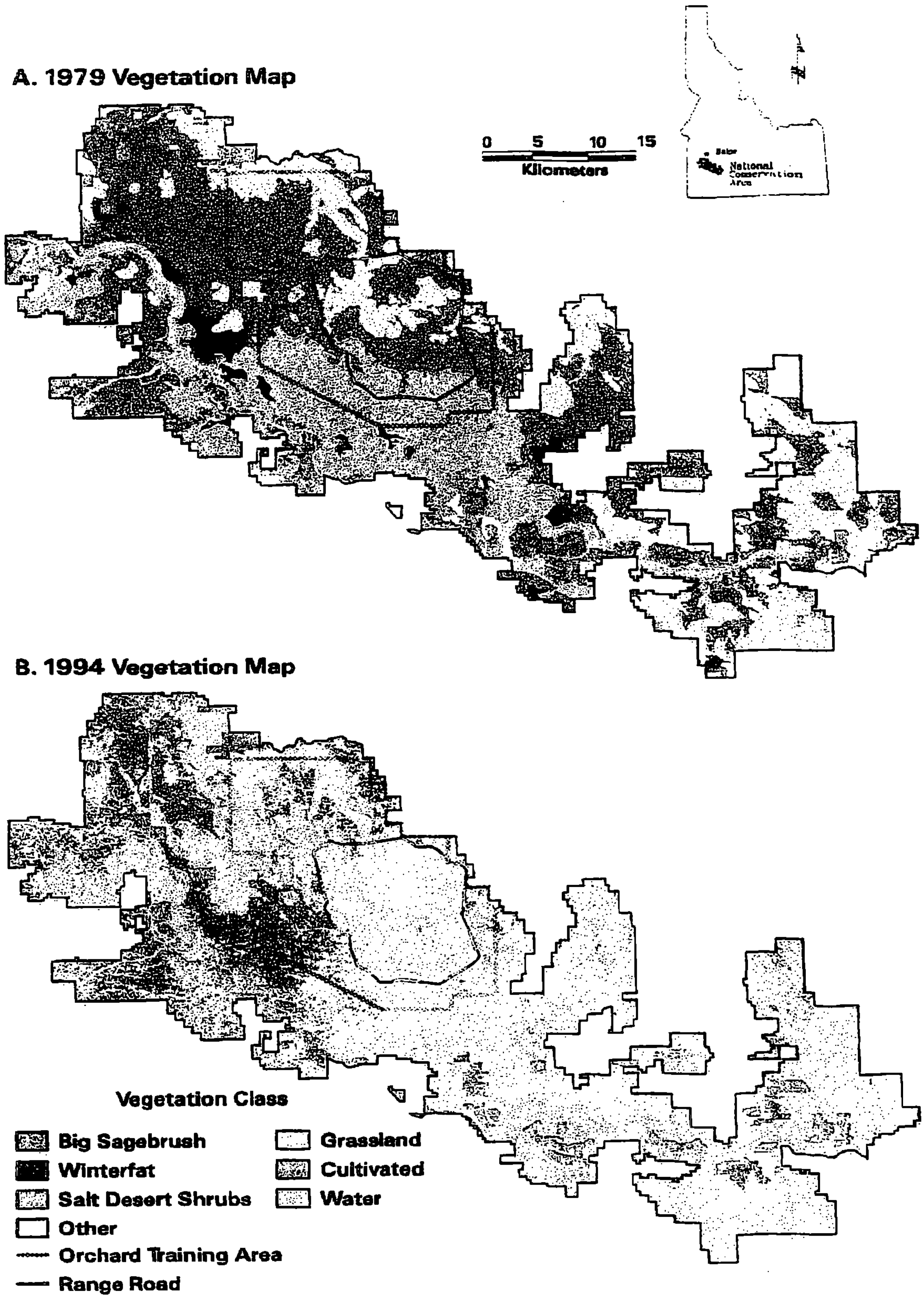


Figure 6. Vegetation changes in the Snake River Birds of Prey National Conservation Area from 1979 to 1994. Native shrubs and grasses have decreased substantially and exotic annual grasses have increased in dominance in a relatively short period of time. Changes in habitat may affect populations of birds and other wildlife.

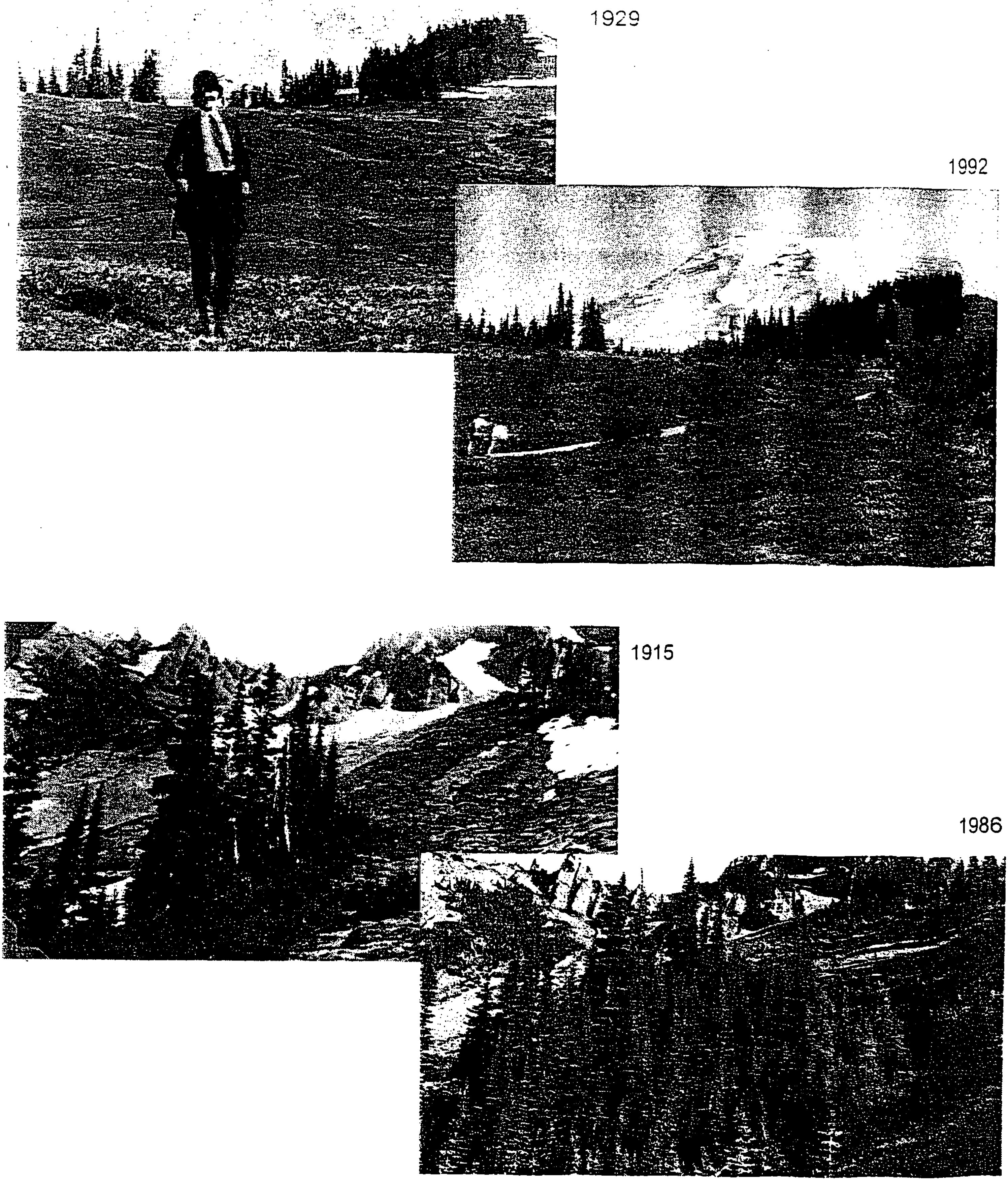
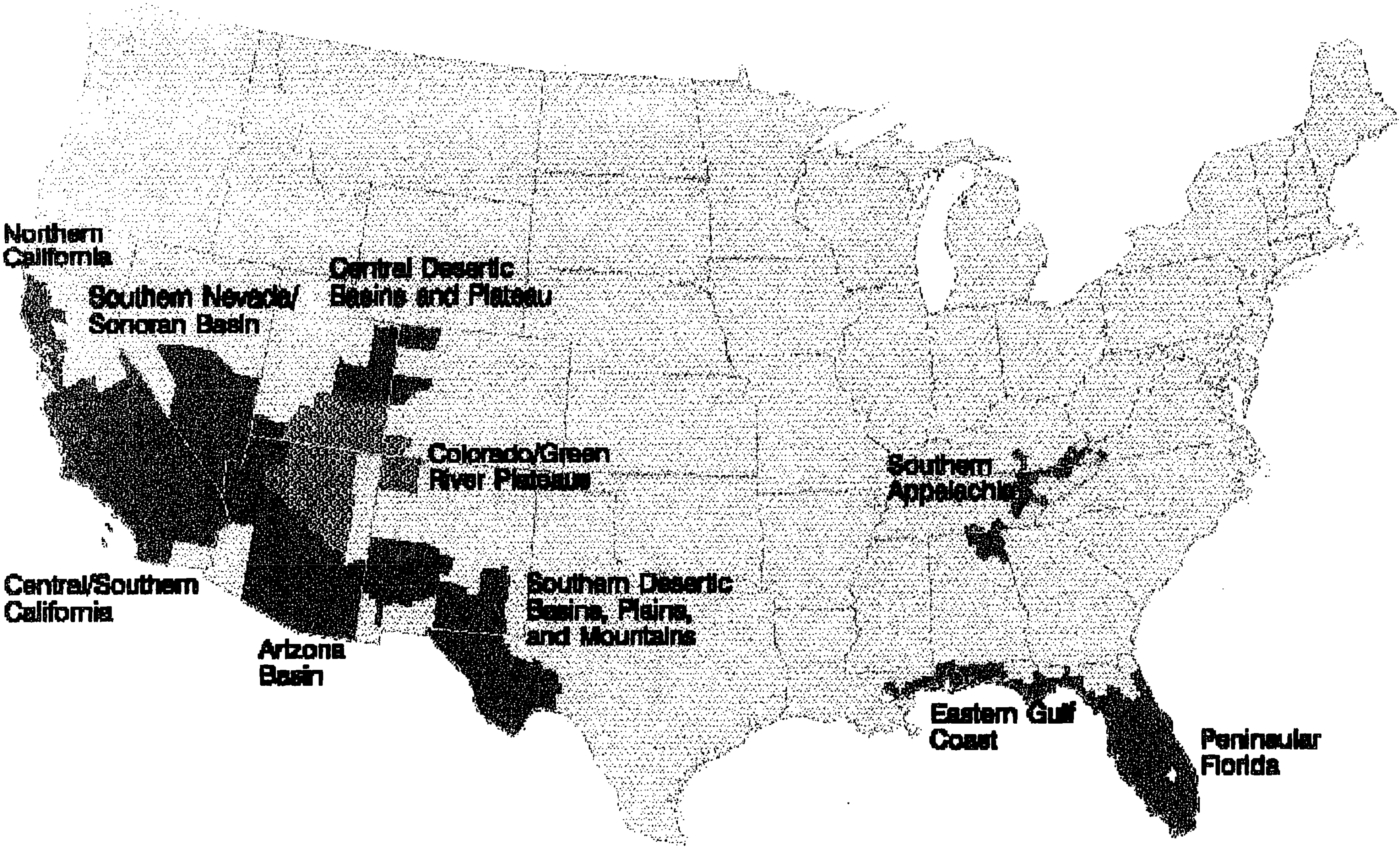


Figure 7. Paired photos of sites in Mt. Ranier (above) and Olympic National Park (below), showing recent tree establishment associated with a warmer, drier climate.

Figure 8. Regions of species endangerment in the conterminous US, based on numbers of endangered species by counties grouped according to similar climate, physiography, soils, vegetation, and land use.



The Atlanta Journal-Constitution

LOCAL NEWS

Senate vote lifts ban on logging in Georgia

Friday, September 10, 1999

Washington -- The Senate endorsed legislative language Thursday that would enable federal land management agencies to get around court rulings that temporarily have stopped logging in national forests in Georgia and the Pacific Northwest.

By a 52-45 vote, the Senate refused to remove a provision from a fiscal 2000 spending bill that would effectively overturn a February decision by the 11th U.S. Circuit Court of Appeals in Atlanta and a subsequent ruling by a federal judge in Washington.

Sen. Max Cleland (D-Ga.), who along with Sen. Chuck Robb (D-Va.) had offered an amendment to strike the provision, called the vote "a defeat for anyone who cares about our national forests."

But Sen. Paul Coverdell (R-Ga.), one of the Republican senators who had inserted the provision in the spending bill, said the court rulings, if allowed to stand, would end the productive use of public lands.

He said they would "make all the national public forests a wilderness area, i.e. untouchable, not only for logging but for recreation and other pastime activities."

Environmental groups waged an all-out campaign to defeat the provision once it was inserted into the spending legislation last summer by Coverdell and fellow GOP Sens. Slade Gorton of Washington and Larry Craig of Wyoming.

It was prompted by the 11th Circuit ruling that halted seven timber sales on 2,100 acres in the Chattahoochee National Forest because the Forest Service failed to assess the potential impact of the logging on endangered and threatened species and on plants and animals that serve as indicators of forest health.

The appellate judges said such studies are required by the 1976 National Forest Management Act. The Forest Service then suspended 25 other pending timber sales in the Chattahoochee, totaling about 6,000 acres, until it completed a review of its species-monitoring program.

A similar ruling last month by U.S. District Court Judge William Dwyer put 217 million board feet of timber harvests in the Pacific Northwest on hold.

In seeking to strike the provision offered by the GOP senators, Robb argued that it would eliminate the requirement that the Forest Service regularly update its data on threatened and endangered species on federal lands.

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"There is no good science without good data," he said.

But Gorton argued that the species-monitoring surveys required by the courts would be so expensive they would effectively end any logging or other use of public lands.

The Clinton administration opposed the provision.

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Global Change Research Program

Research at the USGS contributes directly to the multi-agency U.S Global Change Research Program's intellectual framework of a whole-system understanding of global change (i.e., the interrelationships among climate, ecological systems, and human behavior).

The USGS examines terrestrial and marine processes and the natural history of global change, including the interactions between climate and the hydrologic system. The character of past and present environments and the geological, biological, hydrological, and geochemical processes involved in environmental change are documented.

The USGS is an international source for ground-based and remotely sensed Earth science data, information, and applications, which contributes to assessments of the potential effects of global change on society.

The USGS supports a broad area of global change research that includes an increasing emphasis on understanding the sensitivity of natural systems and impacts of climate change and variability, surficial processes, and other global change phenomena on the Nation's lands and environments at the regional scale. There is also an increasing emphasis on the carbon cycle, with integrated research and modeling of soil dynamics and carbon cycle processes.

Goals
Specific goals of the overall program are to:

- Improve the utility of global change research results to land management agencies;
- Emphasize monitoring the landscape and developing technical approaches to identifying and analyzing changes that will take advantage of a burgeoning archive of remotely sensed and in situ data;
- Emphasize biogeographic regions and features particularly montane, coastal and inland wetland ecosystems.

Activities
In direct support of the U.S Global Change Research Program, the USGS includes activities in the following areas:

Biogeochemical Cycling - Research is developing an understanding of the exchanges of water, energy, and nutrients between the atmosphere and land surface. The processes that control the cycling and fate of carbon and other nutrients in soils, rivers, lakes, reservoirs, and estuarine systems are critical to understanding issues related to erosion, sediment transport, biogeochemical budgets, snowpack chemistry, surface hydrology, and climate response.

Climate and Land Use History - Climate history research focuses on understanding the rates and magnitudes of decadal to millennial scale natural changes in climate and determining how those changes have affected the environment. These studies contribute to regional and global assessments of climatic change and help evaluate models of regional-scale response to past and likely future changes in global and regional conditions.

Hydroclimatology - This research is composed of three major activities: (1) studies to determine the relations between climatic conditions and regional hydrologic variability, including long-term patterns and trends in hydrologic extremes; (2) monitoring trends in the accumulation and dissipation of snow and ice stored in selected U.S. benchmark glaciers; and (3) development of improved procedures for simulating hydrologic processes and conditions in global climate models.

Impacts on Terrestrial and Coastal Ecosystems, Coastal Wetlands, and Fish and Wildlife – This research determines the sensitivity and response of natural systems and ecological processes to multiple environmental factors, including existing climate and natural and anthropogenic impacts, at the local, landscape, regional, and continental level. It provides the scientific knowledge and technologies for conservation, rehabilitation, and management of sustainable ecosystems needed by land management agencies of the Federal and state governments.

Land Surface Characterization – This area includes research and development of techniques to monitor, analyze, describe, apply, and predict land use, land cover, and other surface characteristics data. Data sets are used to characterize and map the Earth's surface, model land surface processes, detect changes over time, and forecast the response of the land surface to changes in climate, environment, land use, and land cover.

Mississippi Basin Carbon Project - Studies are developing a quantitative understanding of the role of land-use change and associated erosion and sedimentation processes on carbon storage and nutrient cycles within the Mississippi Basin. Rates of organic carbon accumulation, erosion, and burial are used to develop whole-basin models of these dynamic relationships.

Satellite Data Management and Dissemination - The USGS continues to operate and enhance the capabilities of the EROS Data Center to serve as the National Satellite Land Remote Sensing Data Archive, by maintaining existing datasets, adding new data sets, and converting older data sets from deteriorating media to modern, stable media. The EROS Data Center also maintains and expands the Global Land Information System (GLIS) to provide information about and access to the Center's many land-related data sets.

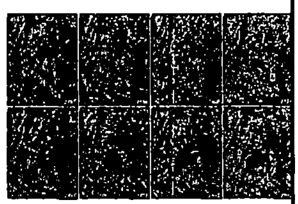
Terrestrial Earth Surface Processes - Research examines the impact of climatic variability and change on earth surface processes, including vegetation change, soil and sediment dynamics and carbon sequestration. A detailed history of vegetation change in the Western U.S. and southern Alaska is being constructed. Data sets and techniques are being developed to forecast the effects of possible future regional- and global-scale vegetation changes. Alaska soil carbon and fire history studies will be expanded.

Related Research:

- Collection, maintenance, analysis, and interpretation of short- and long-term land, water, geological and biological processes and resources through field research and dispersed observing networks;
- Inventorying and monitoring of biological habitats, resources, and diversity;
- Research in land use and land cover, including creation of maps and digital data products;
- Support for Landsat 7.

Global Change Research at the U.S. Geological Survey

USGS



- USGS contribution to science program
- USGS response to National Assessment

USGS

Program Structure

- Climate history
- Monitoring and processes
- Modeling and forecasting
- Land surface characterization
- Satellite data management and dissemination
- Impacts on terrestrial and coastal ecosystems, inland wetlands, and fish and wildlife
- Biogeochemical cycling
- Hydroclimatology

USGS

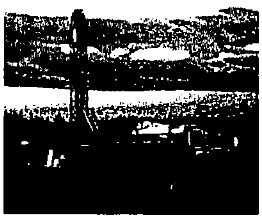
Current Research Examples

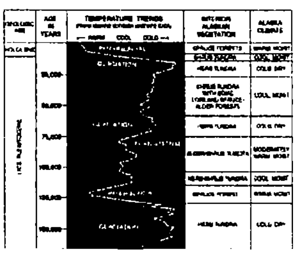
- Alaskan Quaternary climate change
- Glacier monitoring and mapping
- Sand movement
- Vegetation simulations
- Land characterization data set development and application
- Temporal urban mapping
- Satellite data archive
- Global Land Information System (GLIS)
- Threatened coastal habitats
- Wildland fire in forested ecosystems
- Amphibian decline
- Salmon growth and production
- Water, Energy, and Biogeochemical Budget Study sites
- Forecasting Spring runoff
- Mississippi River Carbon
- Rio Puerco River Basin

Climate History

- Develop high quality records of past climates and environments and provide synoptic reconstructions of past climate conditions
- Determine the natural range of climate variability on time scales ranging from interannual to thousands of years
- Identify and characterize conditions during intervals of rapid change
- Determine the response of natural systems, climate-sensitive regions, and ecotones to past change, especially abrupt change
- Develop regional to global scale paleoenvironmental reconstructions for key intervals and events of the past

Alaska Quaternary Climate Change



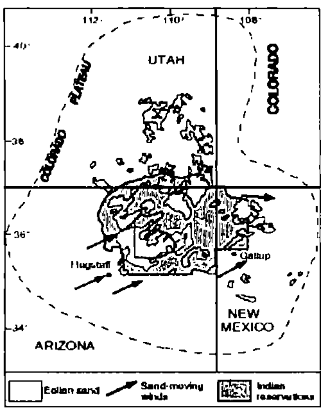


- Combining existing data for the Pacific Ocean with drilling cores to reconstruct detailed vegetation history
- Focus on last 14,000 to 130,000 years

Monitoring and Processes

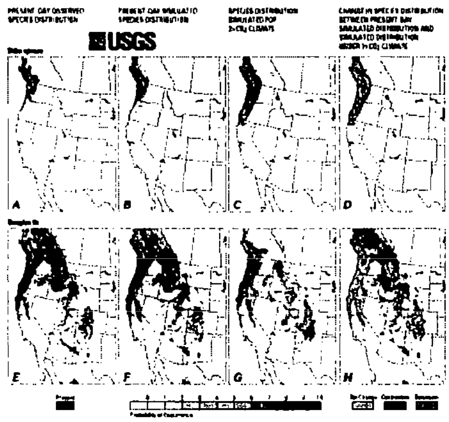
- Monitor selected components of the Earth's climate system
- Improve understanding of biogeochemical cycling of carbon and key nutrients in terrestrial and coastal areas
- Understand rates and history of key processes and land surface response in areas highly sensitive to changes in climate and human activities

Southwest Climate Impacts



- Establishing monitoring stations
- Understanding how climate and human activities impact geologic processes and vegetation changes
- Feeding models of landscape response

Modeling and Forecasting



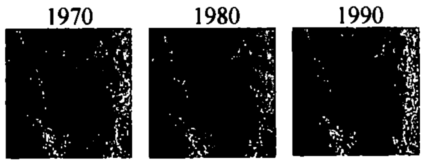
- A strategy to assess regional sensitivity to global climatic change
- Makes use of a hierarchy of models ranging from an AGCM, to a regional climate model, to landscape-scale process models of hydrology and vegetation

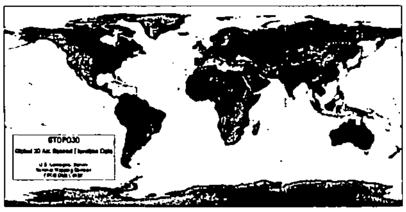
USGS

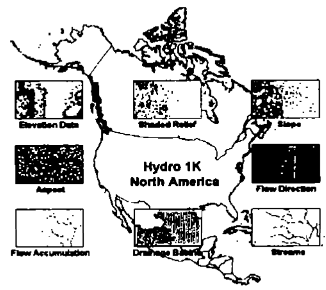
Land Surface Characterization

- Develop techniques to represent and model the Earth's land surface at multiple scales
- Develop global- and regional-scale land cover, elevation, and derivative data
- Apply land surface data to environmental modeling and resources management challenges

Land Surface Characteristics







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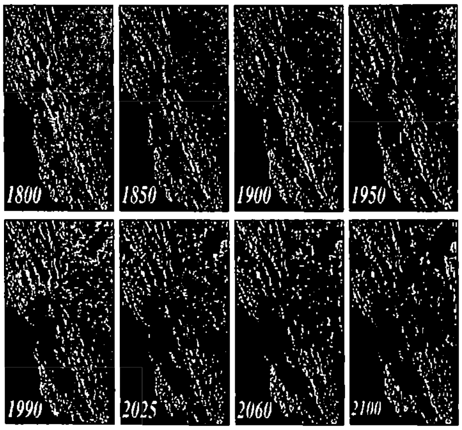
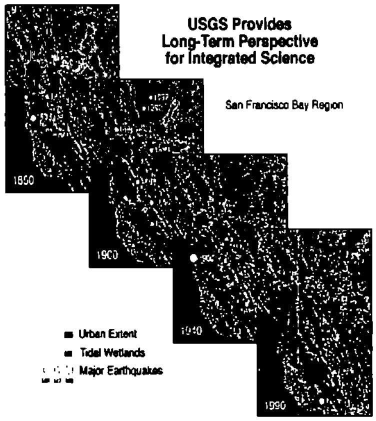
Land Surface-Related Data Set Applications

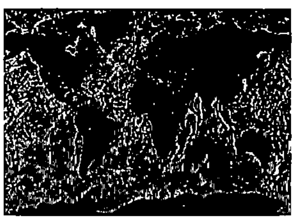
- Investigate the role of land cover type and spatially heterogeneous landscape patterns in mesoscale atmospheric circulations and regional weather
- Sensitivity analyses of the effect of land cover on precipitation, temperature, and evaporation
- Estimating natural volatile organic compound emissions (biogenic emissions) as a function of vegetation species composition, landscape heterogeneity, seasonal variations in foliar biomass

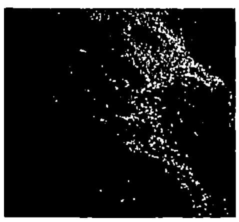
Dynamic Landscapes

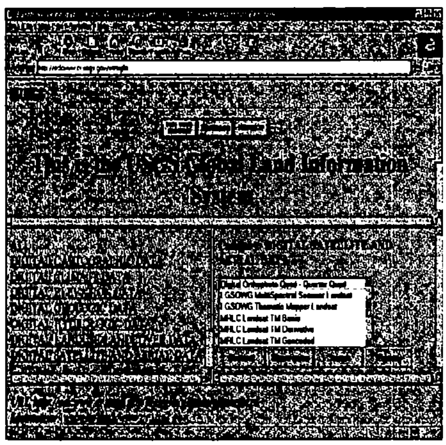




Satellite Data Management and Dissemination







Impacts on Terrestrial and Coastal Ecosystems, Inland Wetlands, and Fish and Wildlife

Grinnell Glacier from Grinnell Lake
Glacier National Park, 1910-1997

- Determine sensitivity and response of ecosystems and ecological processes to environmental factors including existing climate
- Assess and predict how future environmental conditions may affect ecosystems
- Provide scientific knowledge and technologies needed for conservation, rehabilitation, and management of sustainable ecosystems

Impacts on Terrestrial and Coastal Ecosystems, Inland Wetlands, and Fish and Wildlife

- Determine impact of sea level variability and climate change on coastal lands and coastal barrier ecosystems and their biological diversity
- Assess ability of coastal lands to adapt to sea level rise, evaluate mitigation strategies, and provide information for ecosystem management of natural and developed coastal barriers
- Determine the response of wetlands to climate change and provide potential scenarios for future climate change

Impacts on Terrestrial and Coastal Ecosystems, Inland Wetlands, and Fish and Wildlife

- Past changes in fire frequency accelerate and amplify climate change effects
- Investigate sensitivity of fire regimes to climate
- Evaluate alteration of fire regime through climate change

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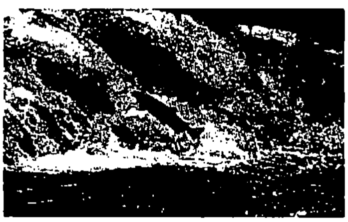
Impacts on Terrestrial and Coastal Ecosystems, Inland Wetlands, and Fish and Wildlife



- Develop long-term monitoring projects to document changes and assess impacts of climate variability on abundance and distribution of fish and wildlife
- Determine how climate change and other environmental stressors may affect habitat quality, population viability, species abundance and distribution, changes in migratory patterns, and physiological response of species

USGS

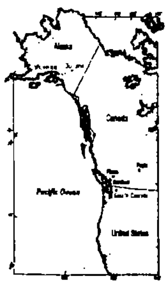
Biogeochemical Cycles

- Understand CO2 and CH4 cycling in rivers, lakes, and reservoirs
- Investigate water, energy, and biogeochemical exchanges between the land surface and the atmosphere

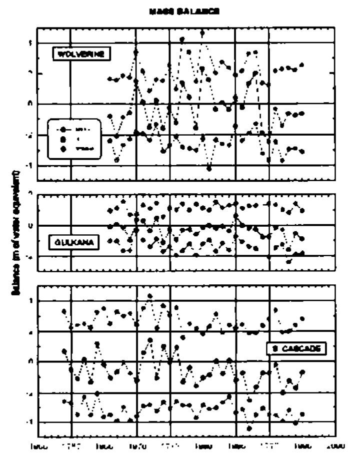
Hydroclimatology

- Understanding relationships between climate and regional hydrologic variability
- Monitoring behavior of snow and ice
- Developing procedures for simulating hydrologic processes and conditions in GCMs

Benchmark Glacier Mass Balance



- Mass balance calculations in meters of water equivalent for the Wolverine, Gulkana, and South Cascades glaciers



Forecasting Spring Runoff

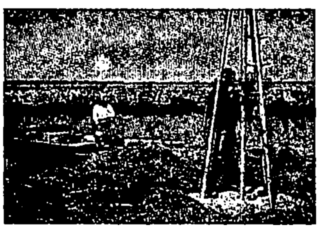
- Using temperature predictions to forecast spring runoff surges from the Sierra Nevada
- Developing and calibrating a spatially detailed, physically based hydrologic model of the Merced River
- Available weather predictions may offer opportunities to predict regional-scale, short-term events

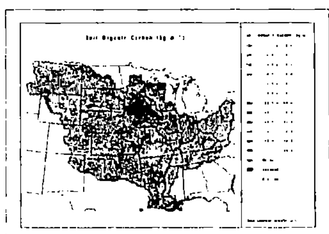
USGS

Mississippi River Basin Carbon

- Examining interactions between global carbon cycle and human-induced changes to the land surface
- Quantifying the interactive effects of land-use, erosion, sedimentation and soil development on carbon storage and nutrient cycles within the Mississippi River basin
- Two hypotheses: carbon is buried on toe-slopes and in reservoirs and carbon fixation on moderately eroded sites is higher than previously expected and carbon is fixed in waterways

Mississippi River Basin Carbon





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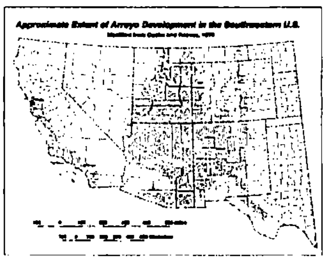
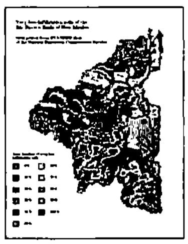
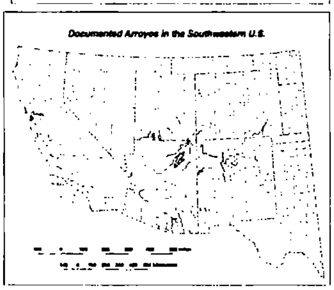
Rio Puerco River Basin

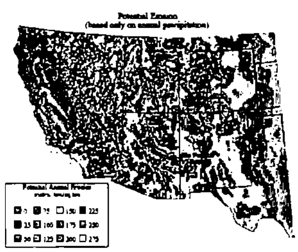
- Integrating data and information from various USGS program components
- Investigating the impacts of climatic, hydrologic, geomorphic, geochemical, and human processes in an arid/semi-arid landscape
- Focus on the Rio Puerco River basin west of Albuquerque NM

Rio Puerco River Basin





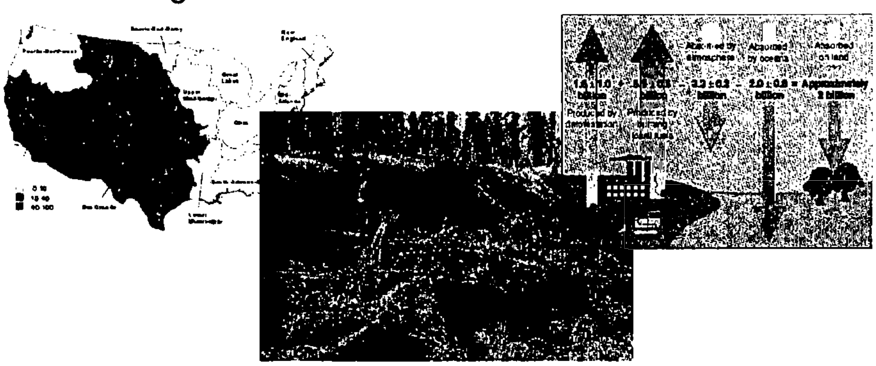




Rio Puerco Then and Now

Future Directions

- Regional studies and impact assessments
- Carbon cycle
- Decision support for land and water resource managers



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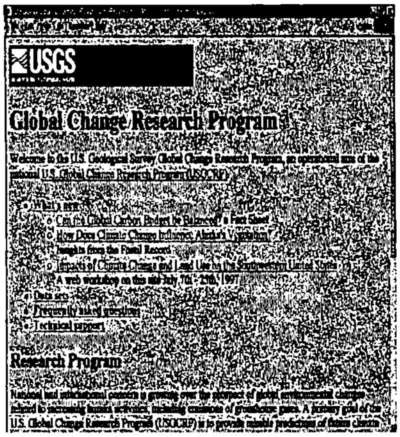
Accessing USGS Global Change Research Information



- Principal entry point http://geochange.er.usgs.goc
- Provides links to research within the USGS and to other USGCRP sites

science for a changing world

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Global Change Research Program

The USGS Global Change Research Program is a component of the U.S. Global Change Research Program (USGCRP), complementing research and observations on oceanic, atmospheric, and biological processes in other Federal agencies. The USGS is an international source for ground-based and remotely sensed earth science data and information used by global change researchers and contributing to assessments of the potential effects of global change on society. USGS global change research examines terrestrial and marine processes and the natural history of global change, including the interactions between climate and the hydrologic system. The USGS documents the character of environments in the past and present, and the geological, biological, hydrological, and geochemical processes involved in environmental change.

- **What's New?**
  - New U.S. Carbon Cycle Science Program
  - A Strategy For Assessing Potential Future Changes in Climate, Hydrology, and Vegetation in the Western United States
  - An Illustrated Diary of Summer 1998 Field Investigations in Southern Alaska
  - Rio Puerco Basin Studies
  - A Devil's Hole Primer
  - Coastal Change and Glaciological Maps of Antarctica
  - The Carbon Cycle in Lakes of the Upper Mississippi Basin

- **Assessing the Impacts of Climate Variability and Change on the Nation's Resources**
  - Potential Consequences of Climate Variability and Change to Water Resources of the U.S.

- **Web Workshop: Impacts of Climate Change and Land Use on the Southwestern U.S.**
  World-Wide Web workshop highlighting issues and research activities in the Southwest

- **Fact Sheets**

- **Current research activities:**

- Carbon Cycle Research
- Earth Surface Dynamics
- Hydroclimatology
- Impacts on Biological Resources
- Land Characterization and Satellite Data Management
- Rio Puerco Basin Studies

- **Available Data Sets**

- **Frequently Asked Questions**

USGS Biology Geology Mapping Water Search USGS

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U.S. Global Change Research Program
Carbon Cycle Science Program
An Interagency Partnership

Program Description

Program & Science Planning

Current Research Activities

Contacts

Overview

Rising atmospheric carbon dioxide concentration and its potential impact on future climate is an issue of global economic and political significance. The need to understand how carbon cycles through the Earth system is therefore critically important to our ability to predict any future climate change. Recent policy debates have demonstrated the need for a comprehensive, unbiased scientific understanding of sources and sinks of carbon dioxide on continental and regional scales, and how sinks might change naturally over time or be enhanced by human activities. The National Research Council's report, "Global Environmental Change: Research Pathways for the Next Decade," specifically emphasizes the need for a comprehensive carbon cycle research strategy.

The U.S. Global Change Research Program (USGCRP) is answering this call by establishing the **Carbon Cycle Science Program**. The new Program is poised to provide critical unbiased scientific information on the fate of carbon dioxide in the environment to contribute to the ongoing public dialogue. The Program will provide the scientific foundation for estimating the capacity of the land and the ocean to sequester and store the considerable quantities of carbon dioxide anticipated from human activities in the future.

Research will be coordinated and integrated to identify and quantify regional to global scale sources and sinks for carbon dioxide and other greenhouse gases and to understand how these sources and sinks will function in the future, providing essential information for future climate predictions. An interagency working group is developing implementation plans. A scientific working group was established in the spring of 1998 and is presently completing a comprehensive science plan for integrated research. Implementation of the new program will require a significant investment of resources and a high level of interagency coordination and integration.

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Global Change Research Program

USGS Carbon Cycle Research

The U.S. Carbon Cycle Science Program (CCSP) is an interagency partnership that draws on the expertise and ongoing research in seven agencies, with the objective of developing a whole-system predictive capability for the global carbon system. The ultimate goal is to provide integrated estimates of carbon sources and sinks, with a focus in FY 2000 on implementing activities to determine the magnitude, location, and cause of the North American terrestrial sink. The program will develop the understanding of how sinks might be enhanced and how they might change in the future, information that is of critical importance to potential decisions to manage the carbon system.

USGS research is conducted in cooperation and partnership with other agencies and academic collaborators. In direct support of the Carbon Cycle Science Program, the USGS activities include the following:

Carbon sequestration in sediments - Redeposition of eroded soils and sediments and their associated organic carbon is sequestering large quantities of carbon, buried at the base of slopes and in wetlands, riparian areas, reservoirs, etc. Field-based measurements and modeling are developing a quantitative understanding of the role of land-use change and associated erosion and sedimentation processes on carbon storage and nutrient cycles within the Mississippi Basin. Rates of organic carbon accumulation, erosion, and burial are being used to develop whole-basin models of these dynamic relationships.

- Mississippi Basin Carbon Project Fact Sheet
- Mississippi Basin Carbon Project Science Plan
- Carbon Cycle in Lakes of the Upper Mississippi Basin

Landscape dynamics and vegetation change - Research examines the long-term dynamics of vegetation change and the impact of climate. A detailed history of vegetation change in the Western U.S. is being constructed based on the paleobotanical record of pollen and plant tissues preserved in packrat middens and buried in sediments. Large data sets and techniques are being developed to model and forecast the effects of possible future climate change on vegetation at regional and global scales. Models will be enhanced in the future to include the associated soil carbon.

- Modeling Vegetation Response to Climate Change

Fate of Carbon in Alaskan Landscapes - Cold region forests (boreal ecosystems) contain large carbon reserves that are today highly susceptible to changes in climate. Soils and wetlands comprise more than 2/3 of the boreal C reserves, and changes in fire and seasonal temperatures may cause changes in ecosystem structure, permafrost recovery, nutrient cycling, and carbon exchange. Central to the fate of these C reserves is the interaction between fire occurrence and permafrost changes in the surface layers. Process studies and modeling are being expanded to better understand the historic and modern interactions among climate, surface temperature and moisture, fire, and terrestrial carbon sequestration.

- Fate of Carbon in Alaskan Landscapes

Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface - Atmospheric turbulence transports greenhouse gases (notably: carbon dioxide (CO_2), methane, and nitrous oxide), water vapor, and heat between Earth's land and water surfaces and the overlying atmosphere. These exchanges influence climate, viability of ecosystems, distribution of biomes, and the quantity of both surface- and ground-water. USGS researchers and their collaborators are directly measuring the exchanges of greenhouse gases, water vapor, and heat to better understand interactions between Earth's surface and atmosphere.

- Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface

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U.S. Geological Survey
Global Change Research Program
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Global Change Research Program

Assessing the Impacts of Climate Variability and Change on the Nation's Resources

Since 1990, the U.S. Geological Survey has been participating in the U.S. Global Change Research Program--a comprehensive and integrated research initiative to understand, assess, predict, and respond to human-induced and natural processes affecting the Earth's environment.

In 1997 the program began a national assessment of the impacts of climate variability and change. The assessment will apply what research is finding to help understand the potential impacts, both detrimental and beneficial, that global change may have on the environment, society, and the economy.

- **National Assessment Overview**
- **Assessing Climate Change Impacts in Alaska**
- **The Arid and Semi-Arid Western United States**
- **Impacts on National Parks, Refuges, and Other Public Lands**
- **Impacts on Water Resources**
  - Potential Consequences of Climate Variability and Change to Water Resources of the U.S.

U.S. Department of the Interior
U.S. Geological Survey
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<http://climchange.cr.usgs.gov/info/assessment/index.html>
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U.S. GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
GLOBAL CHANGE HYDROLOGY PROGRAM

Purpose -- To develop data, understanding, and predictive capability related to water and associated aspects of carbon and greenhouse gases and their interactions with global systems.

Organization-- Component of USGS Global Change Research Program, which is in turn a component of the U.S. Global Change Research Program (USGCRP). The Global Change Hydrology program itself has two components --

- hydroclimatic variability
- biogeochemistry of greenhouse gases

Hydroclimatic variability -- studies of temporal and spatial variations of streamflow and glacier volumes and associated hydrologic and climatic variables.

- Hydrology in general circulation and regional climate models
- Glacier mass balance and snowpack
- Streamflow trends and fluctuations and linkages to climate variation
- Seasonal runoff timing
- Climatic effects on estuaries
- Biotic response to climate variability
- Fluvial geomorphic response to climate change
- Paleoflood studies
- Paleoclimatology and aquifer geochemistry
- Arid regions climate and lakes

Biogeochemistry of greenhouse gases -- studies of quantities and movements of carbon and other climatically active substances in streams, lakes, reservoirs, and ground water.

- Water Energy and Biogeochemical Balance study sites
- Gas transport in unsaturated zone
- Biogeochemical interactions at environmental interfaces
- Carbon fluxes in hydrologic and geological processes
- Microbial biogeochemistry of aquatic environments

Contact -- W. Kirby, U.S.Geological Survey, 415 National Center, Reston, VA 20192.
Tel: 703-648-5315 E-mail: wkirby@usgs.gov
http://water.usgs.gov/osw/programs/globalchange.html

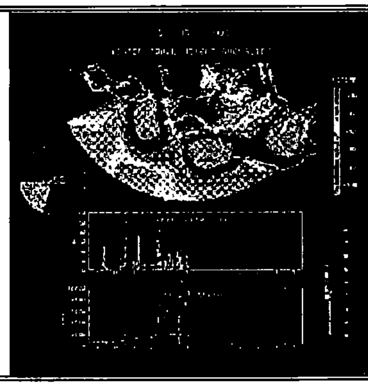
Global Change Hydrology Program (Hydroclimatology)

contact - William Kirby email: wkirby@usgs.gov

Overview

The Global Change Hydrology Program was begun in 1990 to develop data, understanding, and predictive capabilities related to water and associated aspects of carbon and the greenhouse gases as they interact with global systems. The Program is part of the USGS Global Change Research Program (Geochange) which, in turn, is an element of the U.S. Global Change Research Program (USGCRP). Global Change Hydrology has two broad components: 1) investigations of hydroclimatic variability, and 2) studies of the biogeochemistry of greenhouse gases. The former are coordinated by the Office of Surface Water and are described herein. The latter are coordinated by the Office of Hydrologic Research, and additional information on those can be obtained at NRP and at WEBB. Both are national in scope and maintain strong programmatic linkages to scientists and projects supported by NSF, NOAA, and NASA.

The hydroclimatic research components of the Program focus on characterizing, and developing predictive methods related to, the hydroclimatology of North America. This includes identification of seasonal variations in regional streamflow in relation to atmospheric circulation (for regional streamflow prediction and flood/drought hazard assessment); the linkage between atmospheric circulation and snowpack accumulation (for forecasting spring and summer water supply in the western United States and for flood forecasting) as well as glacier mass balance; and the physical and chemical variability in riverine and estuarine environments in relation to large-scale atmospheric and oceanic conditions(to discriminate natural from human-induced effects on such systems). It also includes documenting the long-term behavior of hydrologic systems in response to past climatic variations and changes (from decades to hundreds of thousands of years) as well as more recent (decadal) hydrologic trends. Finally, the Program maintains an active effort to develop improved representations of terrestrial hydrologic processes in general circulation and regional climate models. In broad terms, these activities are aimed at improving statistical and deterministic methods for predicting hydrologic hazards and related environmental conditions on monthly to interannual time scales.



Atmospheric circulation over the North Pacific Ocean at 700-mb (about 10,000 feet), and associated precipitation and freshwater inflow from the Sierra Nevada through the Delta to San Francisco Bay on March 17, 1983. The image is a single frame from the hydroclimate and salinity response movie (movie selection index). Click on the image to enlarge

Harry Lins
Office of Surface Water, USGS
March 1998

Research Activities

Hydrology in General Circulation and Regional Climatic Models
- Continental hydrology and global climate
- Regional climate model hydrology

Hydroclimatic variability
- Observed streamflow trends
- Detecting runoff trends
- Estuarine effects
- Response of fluvial systems
- Forecasting spring runoff pulses
- Biotic response

Glacier, snow and ice processes
- Glacier mass balance and snowpack

Paleohydrologic conditions
- Continental paleoclimates
- Paleoflood hydrology

Data Sets

HCDN Hydro-Climatic Data Network
GREDS GEWEX Continental-scale International Project Reference Data Set
Benchmark Glacier Data
Devils Hole Core DH-11

Fact Sheets

OFR93-642 Drought
FS-062-95 Northern California Storms and Floods of January 1995
SF-Bay Seasonal/Yearly Salinity Variations in San Francisco Bay
Devils Hole Primer

Links to Other USGS Global Change Sites

WEBB Water, Energy, and Biogeochemical Budgets Research Watersheds
- Luquillo Mountains, Puerto Rico
- Panola Mountain, Georgia
- Sleepers River, Vermont

North Temperate Lakes, Wisconsin
Loch Vale, Colorado

Geochange USGS Global Change Research Program

Publications

Publications of the Global Change Hydrology (Hydroclimatology) Program, 1988 - Present

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We want your feedback!

Programs	Publications	Data	Equipment & Facilities	Techniques	Special Topics	Other sources

U.S. Department of the Interior, U.S. Geological Survey
Maintainer: Office of Surface Water
Last update: 08:10:00 Thu 17Jun1999
URL: http://water.usgs.gov/public/osw/programs/globalchange.html

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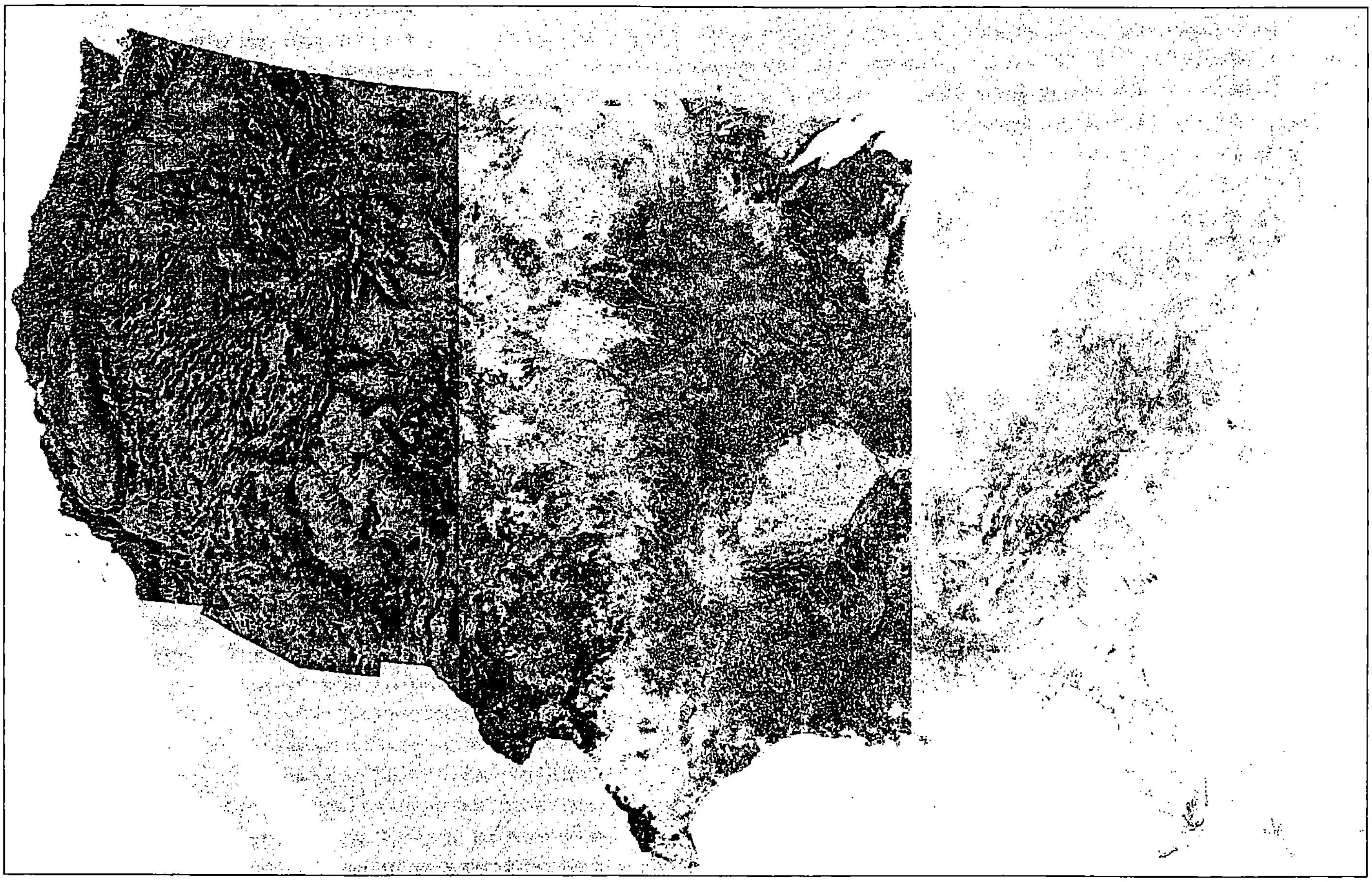
Land Cover Characterization Program

Fact Sheet



Advanced very high resolution radiometer (AVHRR) images of the United States. At left is the mosaicked three-band false color image; the center image shows the seasonal land cover classes derived from the AVHRR data combined with topographic, climatic, and soils information; normalized difference vegetation index (NDVI) is shown on the right, another product from the AVHRR data that combines two bands to derive relative vegetation greenness. All of these products are used regularly in a variety of applications.

The U.S. Geological Survey (USGS) has a long heritage of leadership and innovation in land use and land cover mapping. The USGS Anderson system defined the principles for land use and land cover mapping that have been the model both nationally and internationally for more than 20 years. The Land Cover Characterization Program (LCCP) is founded on the premise that the Nation's needs for land cover and land use data are diverse and increasingly sophisticated. The range of projects, programs, and organizations that use land cover data to meet their planning, management, development, and assessment objectives has expanded significantly. The reasons for this are numerous, and include the improved capabilities provided by geographic information systems, better and more data-intensive analytic models, and increasing requirements for improved information for decision making.

The overall goals of the LCCP are to:
(1) identify the broad range of user requirements;
(2) identify sources, develop procedures, and organize partners to deliver data and information to meet user requirements.

The LCCP builds on the heritage and success of previous USGS land use and land cover programs and projects. It will be compatible with current concepts of government operations, the changing needs of the land use and land cover data users, and the technological tools with which the data are applied. The Program is founded on the following guiding principles:

Guiding Principles

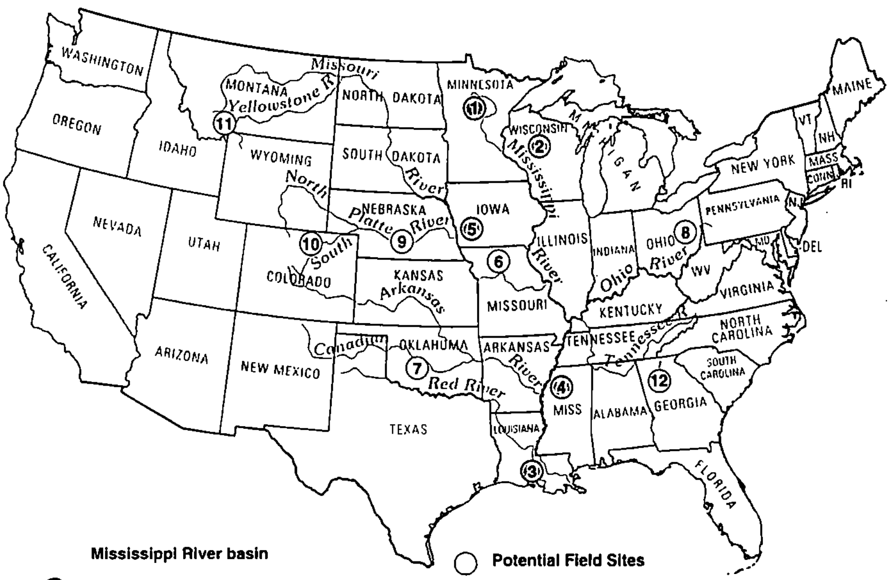
- Compatible with Previous USGS and Other Federal Agency Programs
- Built on Partnerships
- Flexible Database Strategy
- Multiresolution Databases
- Needs Based and User Driven
- Dynamic, with Monitoring Capability
- Integrated Strategy of Research and Production

Program Components

Three of the four LCCP components, each with unique but complementary land cover, land use, and associated data products, are illustrated on the reverse side. The fourth component, Special Projects, will provide unique land cover characteristics data not provided by the other components.

Can the Global Carbon Budget Be Balanced?

The Mississippi Basin Carbon Project of the U.S. Geological Survey (USGS) is an effort to examine interactions between the global carbon cycle and human-induced changes to the land surface, such as farming and urbanization. Investigations in the Mississippi River basin will provide the data needed for calculating the global significance of land-use changes on land-based carbon cycling. These data are essential for predicting and mitigating the effects of global environmental change.



Mississippi River basin

Existing Field Sites

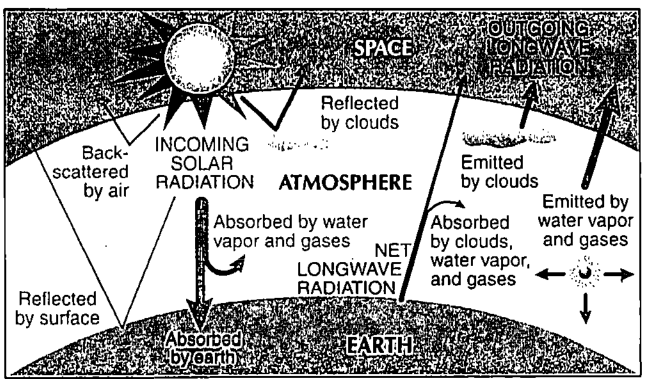
1 Minnesota Lakes, Mississippi River basin
2 Wisconsin Lakes, Mississippi River basin
3 Mississippi River Delta, Mississippi/Atchafalaya River basin
4 Northwest Mississippi, Yazoo River basin
5 Treynor, Iowa, Nishnabotna River basin

Potential Field Sites

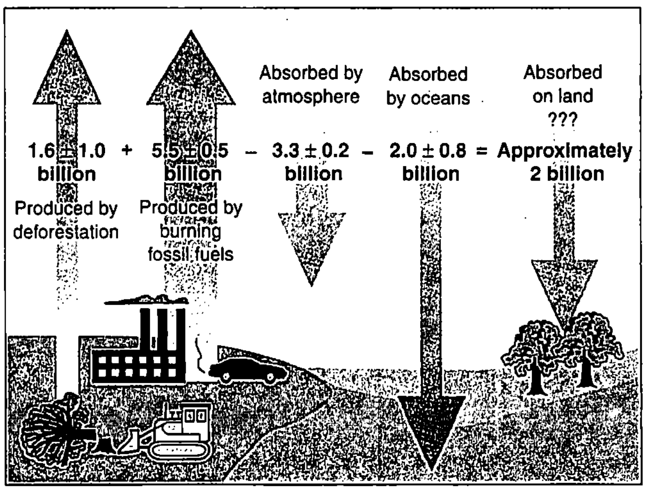
6 North-central Missouri, Missouri River basin
7 Little Washita, Oklahoma, Red River basin
8 Coshocton, Ohio, Ohio River basin
9 Big Bend area, Nebraska, Platte River basin
10 South Platte, Colorado, Platte River basin
11 Headwaters, Yellowstone/Missouri River basin
12 Upper Tennessee River basin

***The Mississippi Basin Carbon Project** is focused on the third largest river system in the world. The Mississippi River and its tributaries drain more than 40% of the conterminous United States. The basin includes areas that typify vast regions of the Earth's surface that have undergone human development.*

Scientists who study the global carbon cycle measure and model transfers of carbon. They account for the numerous additions and subtractions that define the distribution of carbon among the oceans, atmosphere, and land. From studies of the geologic record, it is known that the distribution of carbon among these major reservoirs has changed with past changes in climate. Links between the global carbon cycle and the global climate system are complicated, involving atmospheric carbon dioxide (CO_2) and the "greenhouse effect." Atmospheric CO_2



***The Greenhouse Effect,** which is part of the Earth's climate system, maintains temperatures far warmer than would be expected from direct solar heating. Most of the incoming solar radiation (short wavelength, shown in purple) is absorbed and converted to long wavelength radiation (shown in red), at or near the Earth's surface. Heat results from the absorption of some long wavelength radiation by atmospheric gases, including water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The greenhouse effect is the retention of this heat in the atmosphere. Some human activities increase the amount of greenhouse gases, primarily CO_2, resulting in more heat being retained in the atmosphere.*



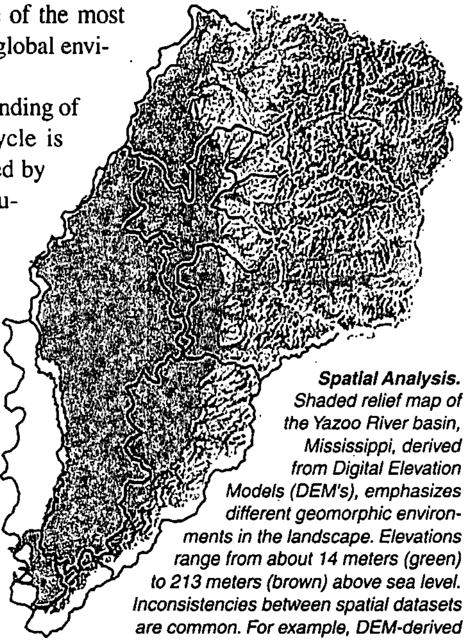
***The Global CO_2 Budget** can be defined as the balance of CO_2 transfers to and from the atmosphere. The transfers shown here represent the CO_2 budget after removing the large natural transfers which are thought to have been nearly in balance before human influence. Units are in metric tonnes of carbon per year. Budget figures shown here are for the 1980's.*

concentrations are presently increasing as a result of human activities. This increase may affect the global climate. Therefore, it is important to understand the global budget of atmospheric CO_2. This challenge has proven to be one of the most difficult problems in global environmental research.

Lack of understanding of the global carbon cycle is perhaps best illustrated by the scientific community's inability to balance the present global CO_2 budget. Before human influences transfers were approximately equalized so that the amount of CO_2 in the atmosphere had remained nearly constant for thousands of years. The increase in atmospheric CO_2 over the last 100 years has primarily resulted from the burning of fossil fuels. However, the concentration of CO_2 in the atmosphere is also influenced by human modifications of the land surface by harvesting forest products, farming, and urban development. These transformations drastically alter the cycle of carbon accumulation and distribution on the land surface.

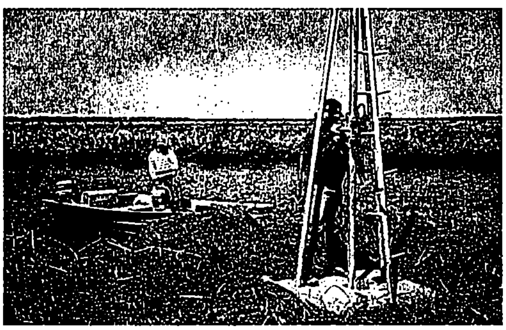
The amount of human induced CO_2 appears to exceed the amount accumulating in the atmosphere and oceans. The carbon needed to balance the CO_2 budget (about 1 to 2 billion metric tonnes per year) is probably absorbed by land plants and ultimately incorporated in soils or sediments. Accumulating evidence points toward this carbon being absorbed in the temperate latitudes of North America, Europe, and Asia.

Carbon cycle interactions can be extremely complex. For example, agricultural practices increase erosion, which tends to decrease the fertility and carbon content of soil, the largest carbon reservoir on the land surface. Some of the carbon depleted by erosion from upland soils is transported downslope and buried at the base of hillslopes, on floodplains, and in reservoirs. Once buried, most of this carbon is no longer available for exchange with the atmosphere. Fertilizer application, however, enhances soil productivity, and freshly eroded substrates enhance the rate of organic matter formation. Thus, while land-surface disturbance increases erosion, which degrades the soil, the combined effects of agriculture and the redistribution of carbon across the landscape may promote carbon accumulation on land.



Spatial Analysis. *Shaded relief map of the Yazoo River basin, Mississippi, derived from Digital Elevation Models (DEM's), emphasizes different geomorphic environments in the landscape. Elevations range from about 14 meters (green) to 213 meters (brown) above sea level. Inconsistencies between spatial datasets are common. For example, DEM-derived watershed boundaries (white lines) above four major reservoirs differ from watershed boundaries (black lines) derived from a national hydrologic unit dataset. Such inconsistencies will be resolved prior to spatial analysis of storage and distribution of carbon in the landscape.*

The primary goal of the Mississippi Basin Carbon Project is to quantify the interactive effects of land-use, erosion, sedimentation, and soil development on carbon storage and nutrient cycles within the Mississippi River basin. The project includes spatial analysis of a wide variety of geographic data; site-specific studies of relevant processes; and estimation of whole-basin and subbasin carbon and sediment budgets, and development and implementation of terrestrial carbon-cycle models. These studies are directed at estimating rates of carbon accumulation, decomposition, erosion, transport, and deposition; and particularly at assessing the sensitivity of these rates to climatic, hydrologic, topographic, and land-use gradients. By investigating how fundamental processes influence carbon in soils and sediments of the Mississippi River basin, we hope to take a step toward understanding the global significance of human effects on land-based carbon cycling.



Site Specific Studies. *Vibracore sampling of marsh peat in the Mississippi River Delta, southern Louisiana. Vibracore is a coring procedure that uses mechanical vibration rather than rotation to force a sampling tube into unconsolidated saturated material. Investigations in the Delta are a collaboration between the USGS and the U.S. Army Corps of Engineers, New Orleans District. (Photo courtesy of Jack McGeehin, USGS, 1996.)*

INTEGRATION OF DATA AND MODEL RESULTS ACROSS SCALES

GIS, REMOTE SENSING, CARBON AND SEDIMENT BUDGETS, HISTORICAL INFORMATION

SITE-SPECIFIC
Hillslope process studies
⇩
INTERMEDIATE
Nishnabotna River basin
⇩
REGIONAL
Missouri River basin
⇩
CONTINENTAL
Mississippi River basin
⇩
GLOBAL
Global carbon cycle, globally-mapped databases, regional and continental studies

***Data Integration** is accomplished through statistical and spatial analysis of model results.*

Studies of carbon, sediment, and nutrient budgets in the Mississippi River basin will also provide valuable information relevant to many problems associated with human land use. Agricultural productivity is threatened by erosion and declines in soil fertility. Erosion and sedimentation are primary concerns in the management of water supplies and quality. Natural organic compounds play a critical role in the transport and storage of contaminants in waters and sediments. Carbon compounds account for most of the oxygen depletion associated with anoxia and eutrophication in lakes, streams, and coastal waters. An improved understanding of interactions between changes in the land surface and changes in the global carbon cycle is essential to predicting and coping with global environmental change.

Helaine W. Markewich, Norman B. Bliss, Robert F. Stallard, and Eric T. Sundquist
Graphic design by *Caryl J. Wipperfurth*
Shaded relief map by *Bruce B. Worstell*

COOPERATING ORGANIZATIONS
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Global Change and Climate History

Magnitude and Significance of Carbon Burial in Lakes, Reservoirs, and Northern Peatlands

Fact: Lakes, reservoirs, and peatlands collectively cover less than 2 percent of the Earth's surface but bury organic carbon at an annual rate that is four times the carbon burial rate in all oceans, which cover 71 percent of the Earth's surface.

Carbon Burial in Lakes

It is estimated that freshwater lakes in the world have a total area of about 1.5×10^{12} m^2 (Shiklomanov, 1993; table 1). Including saline inland seas in this total would add another 1×10^{12} m^2. The 28 largest (area of each > 5,000 km^2) freshwater lakes in the world have a total area of 1.18×10^{12} m^2 or about 79 percent of the total area of all freshwater lakes. If the 28 large lakes bury organic carbon (OC), on average, at the same rate as Lake Michigan (5 $g/m^2/yr$), then the annual rate of OC burial in these 28 lakes is about 6 Tg/yr (6 terragrams per year or 6×10^{12} g/yr; table 1). If the smaller lakes bury OC, on average, at the same rate as an average Minnesota lake (72 $g/m^2/yr$), then the annual rate of OC accumulation in these smaller lakes is about 23 Tg/yr (23×10^{12} g/yr; table 1). If saline inland seas bury OC at the Lake Michigan rate, this would be an additional 5 Tg/yr, for a total of 34 Tg/yr for all freshwater lakes and saline inland seas (table 1). Mulholland and Elwood (1982) estimated the OC burial in all lakes and inland seas (excluding the Black Sea) to be 60 Tg/yr today (table 1) and an average of 20 Tg/yr for the last 10,000 years. Stallard (1998) modeled terrestrial sedimentation as a series of 864 scenarios. For lake area, he used 1.54×10^{12} m^2, the area of the 250 largest lakes in the world. This is close to the total of large and small lakes given in table 1. Again, including inland seas to this total would add an additional 1×10^{12} m^2. Results of scenarios for lakes and reservoirs were divided into two components, those with clastic sediments and those with organic sediments. The results of OC burial in the most likely of Stallard's scenarios for lakes range from 48 to 72 Tg/yr (table 1), the average of which is close to the 60 Tg/yr estimated by Mulholland and Elwood (1982). We will use an average of 54 Tg/yr (table 1). The closeness of these estimates, calculated by different methods, suggests that this value is not in error by more than a factor of two.

Elk Lake, Minnesota, is typical of the many lakes in glaciated parts of the Midwestern United States that bury organic carbon at a rate of about 72 $g/m^2/yr$.

Table 1. Burial of organic carbon.

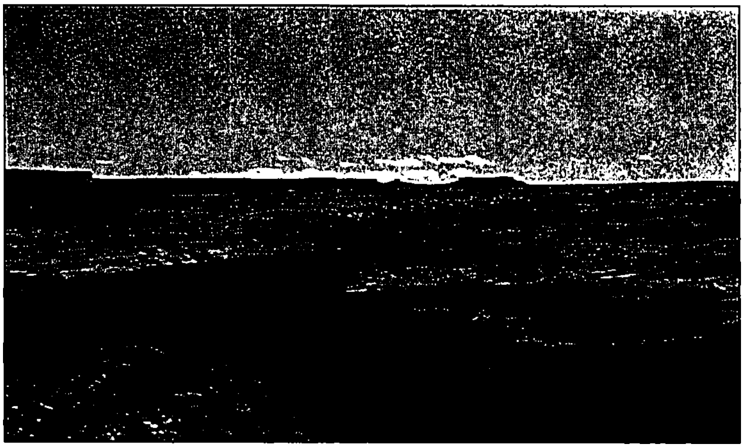
[OC, organic carbon. Large lakes include 28 lakes, each with an area greater than 5,000 km^2]

Location of sediment carbon sink	Area of carbon sink ($\times10^{12}$ m^2)	OC burial rate ($g/m^2/yr$)	Amount of OC buried ($\times10^{12}$ g/yr)
Carbon burial in lakes, reservoirs, and peatlands			
LAKES			
Large	1.18	5	6
Small	0.32	72	23
Inland seas	1.00	5	5
Total	2.50[a]........2.50[a]		34[a]
			60[b]
			48–72[c]
			54[d]..............54[d]
RESERVOIRS	0.40[a]	400	160[a]
	0.66[c]		300–400[c]
			200[b]
	0.53[d]........0.53[d]		265[d]............265[d]
PEATLANDS (present)	3.30[e]........3.30[e]	29	96[e]..............96[e]
TOTAL "LAND" (lakes, reservoirs, peatlands)	**6.33**		**415**
Carbon burial in the world's oceans			
OCEANS			
Margins	42[f]		
Basins	320[f]		
Total	362[f]..........362[f]		60–130[f]
			82[g]
			115[h]
			97[d]..............97[d]
TOTAL "OCEAN"	**362**		**97**
"Land"/"Ocean" quotient	**0.02**		**4.3**

[a]Dean and Gorham (1998). [b]Mulholland and Elwood (1982). [c]Stallard (1998). [d]Mean of above estimates. [e]Gorham (1991). [f]Emerson and Hedges (1988). [g]Sundquist (1985). [h]Arthur and others (1985).

Carbon Burial in Reservoirs

The total area of reservoirs in the world (0.4×10^{12} m^2, Shiklomanov, 1993; 0.66×10^{12} m^2, Stallard, 1998) is smaller than that of lakes, and the average percentage of OC in their sediments (about 2 percent; Mulholland and Elwood, 1982; Richie, 1989) is much less than in most lake sediments. However, because the average sedimentation rate in reservoirs (about 2 cm/yr; Mulholland and Elwood, 1982) is much higher than that in lakes, bulk-sediment accumulation rates are higher, and OC accumulation rates are higher. The main reason that the sedimentation rate is so high in reservoirs is that most are located in arid or semiarid lands underlain by soft, easily eroded sedimentary rock. At an average sedimentation rate of 2 cm/yr, an average bulk density of 1 g/cm^3, and an average OC content of 2 percent, the average OC accumulation rate in reservoirs is 400 g/m^2/yr, and the world's reservoirs are burying OC at a total annual rate of 160 Tg/yr (table 1). This is close to the 200 Tg/yr estimated by Mulholland and Elwood (1982) for the annual accumulation of carbon in reservoirs. Stallard (1998) did a detailed compilation of global reservoir areas and came up with a total area of 0.66×10^{12} m^2 (table 1). The results of OC burial in the most likely of Stallard's scenarios for reservoirs range from 300 to 400 Tg/yr. Thus, the global annual OC burial rate in reservoirs is between 160 and 400 Tg/yr. We will use an average of 265 Tg/yr (table 1).



Lake Powell, Utah, was formed by the damming of the Colorado River behind Glen Canyon dam at Page, Arizona. The drainage basin of the Colorado River is underlain mostly by soft, easily eroded sandstones and shales. The tremendous sediment load delivered to Lake Powell by the Colorado and its upstream tributaries, the Green and Gunnison Rivers, results in the rapid accumulation of sediment behind Glen Canyon dam. The high sediment-accumulation rates in reservoirs globally results in an estimated organic-carbon burial rate in reservoirs of about 400 g/m^2/yr.

Carbon Burial in Peatlands

Wetlands that accumulate more than 30 cm of organic peat are called peatlands (Gorham, 1991). In Europe, they are called mires. Peatlands are concentrated in northern Russia, the Baltic States, Fennoscandia, Canada, and the Northern United States (particularly in Alaska) where they make up 9.7 percent of the total land surface (Gorham, 1995). It is estimated that the total area of unmined northern peatlands is 3.3×10^{12} m^2 (Gorham, 1991). The estimated present average rate of OC accumulation in northern peatlands is 29 g/m^2/yr (Gorham, 1991). Using this rate for all northern peatlands, their total OC burial amounts to 96 Tg/yr (table 1).

Carbon Burial in Oceans

Globally, continental margins only amount to 12 percent of the area of the world oceans, but they are estimated to account for 44 percent of the present burial of OC in the oceans (Emerson and Hedges, 1988). Very little OC accumulates in the deep ocean basins, mainly because any organic matter produced in surface waters decomposes before it gets to the bottom. Estimates of OC burial in all oceans of the world vary, but tend to be about 100 Tg/yr (table 1)

Conclusions

The total annual OC accumulation in lakes (54 Tg), reservoirs (265 Tg), and northern peatlands (96 Tg) is 415 Tg (table 1). Despite the total area of these three carbon sinks being only about 2 percent of the world ocean's surface area, they bury more than four times more carbon than the oceans (table 1).

It should be noted that the drainage of peatlands for forestry and agriculture, and use of peat as fuel, is releasing carbon to the atmosphere. Gorham (1991) estimated that such processes release about 35 Tg/yr from northern peatlands, and more southerly regions may actually be releasing more carbon from drained peatlends than is fixed in undrained sites. On the other hand, cultural eutrophication may have increased lake sedimentation of OC four- to five-fold in small lakes, an increase of 23-32 Tg/yr.

A forested peatland, Shingobee Fen, in northwestern Minnesota. Unlike bogs that receive moisture from precipitation and feed the ground-water table, fens are fed by ground water. This forested fen receives a large discharge of nutrient-rich ground water that provides an environment for rare aquatic plants.

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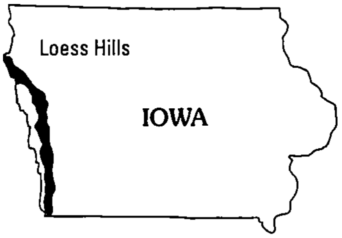
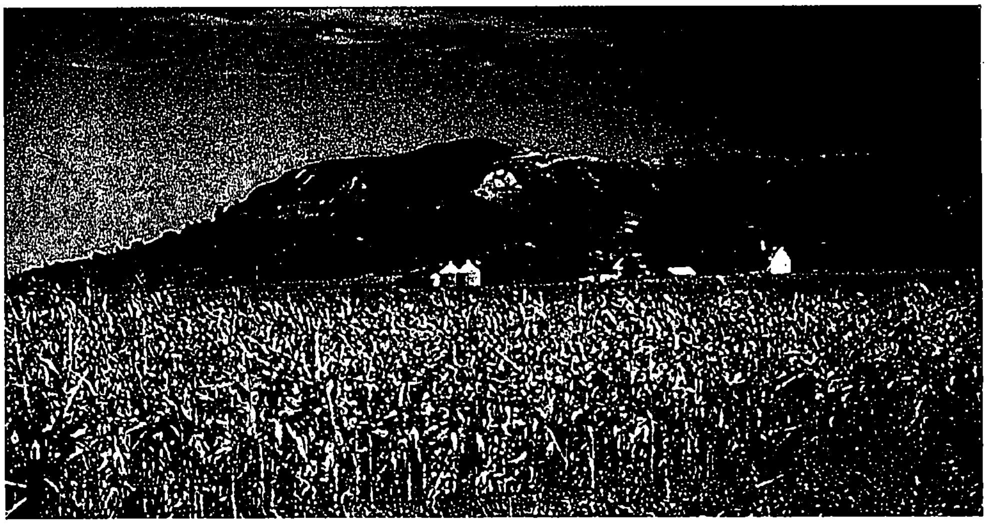
Geology of the Loess Hills, Iowa




The steeply ridged bluffs of the Loess Hills' Murray Hill rise abruptly from the agricultural fields of Iowa. Photo courtesy of the Geological Survey Bureau, Iowa Department of Natural Resources.

Many Americans think of Iowa as having little topographic variation. However, in westernmost Iowa the Loess Hills rise 200 feet above the flat plains forming a narrow band running north-south 200 miles along the Missouri River. The steep angles and sharp bluffs on the western side of the Loess Hills are in sharp contrast to the flat rectangular cropfields of the Missouri River flood plain. From the east, gently rolling hills blend into steep ridges.

Loess (pronounced "luss"), is German for loose or crumbly. It is a gritty, lightweight, porous material composed of tightly packed grains of quartz, feldspar, mica, and other minerals. Loess is the source of most of our Nation's rich agricultural soils and is common in the U.S. and around the world. However, Iowa's Loess Hills are unusual because the layers of loess are extraordinarily thick, as much as 200 feet in some places. The extreme thickness of the loess layers and the intricately carved terrain of the Loess Hills make them a rare geologic feature. Shaanxi, China, is the only other location where loess layers are as deep and extensive. Though much older (2.5 million years) and much thicker (nearly 300 feet) than Iowa's loess, the Shaanxi loess hills have been greatly altered by both natural and human activity and no longer retain their original characteristics.

Origin of the Loess Hills

Although early geologists assumed loess was either fluvial (deposited by a river) or lacustrine (formed in a lake), today we know that loess was eolian (deposited by the wind). During the Ice Age, glaciers advanced down into the mid-continent of North America, grinding underlying rock into a fine powderlike sediment called "glacial flour." As temperatures warmed, the glaciers melted and enormous amounts of water and sediment rushed down the Missouri River valley. The sediment was eventually deposited on flood plains downstream, creating huge mud flats.


Left: Color-infrared image taken 40,000 feet above the Loess Hills. Courtesy of the Geological Survey Bureau, Iowa Department of Natural Resources.

During the winters the meltwaters would recede, leaving the mud flats exposed. As they dried, fine-grained mud material called silt was picked up and carried by strong winds. These large dust clouds were moved eastward by prevailing westerly winds and were redeposited over broad areas. Heavier, coarser silt, deposited closest to its Missouri River flood plain source, formed sharp, high bluffs on the western margin of the Loess Hills. Finer, lighter silt, deposited farther east, created gently sloping hills on the eastern margin. This process repeated for thousands of years, building layer upon layer until the loess reached thicknesses of 60 feet or more and became the dominant feature of the terrain.

Geologic Setting

The Loess Hills are comprised of three major layers. From oldest to youngest, the layers are known as the Loveland Loess, (120,000 to 159,000 years old), the Pisgah Loess (25,000 to 31,000 years old), and the Peoria Loess (12,500-25,000 years old).

Clues in the loess layers help geologists determine the rate at which the loess was deposited. For example, ripples mean accumulation took place very quickly. Thin dark bands in the loess indicate the presence of soil and vegetation which means little or no deposition was occurring.

U.S. Department of the Interior
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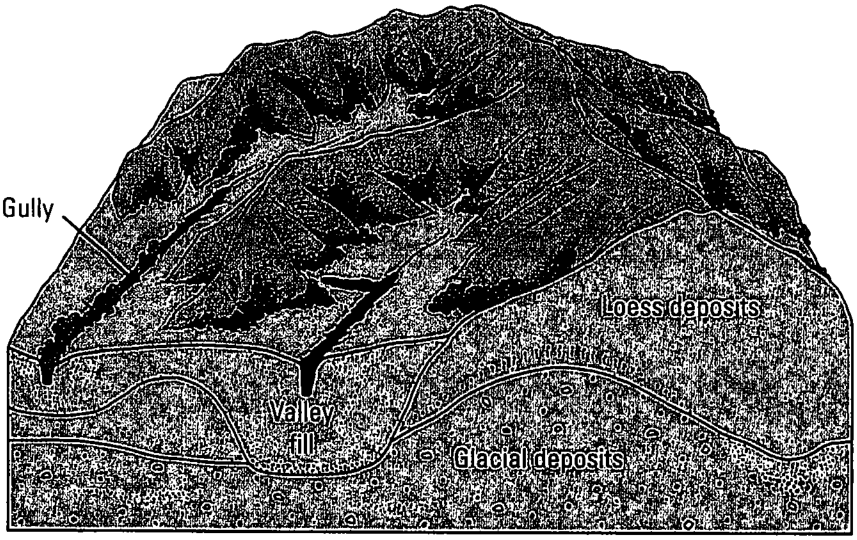
Information Handout
July 1999



Block diagram of the present landscape of the Loess Hills showing features above and below the surface. Adapted from *Landforms of Iowa*, Jean C. Prior, Geological Survey Bureau, Iowa Department of Natural Resources. (University of Iowa Press, Iowa City, 1991). Illustration by Patricia J. Lohmann, p. 49.

Erosion has exposed other geologic formations beneath the loess, such as glacial deposits of sand and gravel and much-older limestone rocks. A 15-inch layer of volcanic ash can be seen in some road cuts, the result of eruptions at now-extinct volcanoes near Yellowstone National Park in Wyoming more than 710,000 years ago. Areas of solid bedrock can be observed in deep quarries along the western edge of the Loess Hills.

The Landscape Today

The Loess Hills are a rare and unusual landform, but they are not permanent; loess terrain is dynamic and rapidly evolving. When originally deposited, the loess was smooth like a sand dune or a snow drift. Today, the Loess Hills are rough and jagged, the result of erosion by the very elements that created them—wind and water.

The pie-crust shapes of these hills are the result of extreme erodibility of loess by wind, water, gravity-induced slipping, and human activity. When dry, loess particles form stable surfaces. Wet loess, however, is very susceptible to collapse and erosion because of a lack of clay particles which normally bond wet soils together.

Erosion has sculpted the Loess Hills into unusual shapes. The irregular ridge crests are called peaks and saddles because they resemble an animal's back. Distinctive staircases-like features on the slopes of some hills are known as catsteps and are actually the result of slipping soil.

Human Interaction

Humans inhabited the Loess Hills as early as 12,000 years ago, but the earliest written descriptions of the Loess Hills appear in journals from the Lewis and Clark Expedition, which travelled through western Iowa in 1804. Later immigrants who settled in and around these hills farmed the fertile rockless soil and grazed cattle on hillsides too steep for planting. The Loess Hills also provide natural resources such as building materials and fill dirt for highways and railroad construction.

Issues Facing the Loess Hills

The Loess Hills of Iowa are extremely fragile. They have one of the highest erosion rates in the U.S., almost 40 tons/acre/year. Erosion from rainfall and flooding removes loess from the hills and redeposits it on the flood plain from which it came. Increased sediment in the streams can be harmful to fish and plants, and drainage ditches must be continually dredged as they become choked with sediment.

Gullies, although a natural part of this landscape, are a serious problem. They can be many miles long, more than 100 feet wide, and as deep as 80 feet. Bridges and roads collapse as the gullies widen, restricting farmers' access to their fields.


The valley floor at the base of the Loess Hills is deeply sliced by steep-sided gullies such as this one. Photo courtesy of the Geological Survey Bureau, Iowa Department of Natural Resources.

Human activities such as farming and mining can exacerbate erosion. Today, farmers practice terracing and contour farming in an effort to limit erosion.

The Loess Hills are home to several endangered plant and animal species. The uniqueness of the landscape and biota led to recognition of portions of the Loess Hills as a National Natural Landmark in 1986 by the U.S. Department of the Interior.

USGS Research in the Loess Hills

As the Nation's largest water, earth, and biological science, and civilian mapping agency, the USGS provides reliable, impartial, scientific information to minimize the loss of life and property from natural disasters, to contribute to the sound conservation, economic, and physical development of the nation's natural resources, and to enhance the quality of life. Current USGS geologic research projects in the Loess Hills include the following:

Loess Hills Erosion

The clearing of land for agricultural use has accelerated the rate of gully formation. Evidence of soil loss and the susceptibility of loess to gully erosion has prompted new research into landscape processes and preservation strategies. The USGS, in conjunction with the Iowa Department of Natural Resources, the Agricultural Research Service, and university researchers, is conducting detailed investigations on erosion rates and the effects of erosion on soils.

Testing Ice-Age Climate Models

Because loess was deposited by Ice-Age winds, it contains a record of past climates in the form of wind direction. Studies show that some of the loess in the Loess Hills came from sources much farther west than the Missouri River valley, indicating the presence of a westerly wind during that time. However, computer simulations show that winds would have come from the northeast. The USGS, in cooperation with the Iowa Department of Natural Resources, is gathering geologic information critical to testing computer models of past climates.

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How Does Climate Change Influence Alaska's Vegetation? Insights from the Fossil Record

Plant fossils, such as leaves, wood, cones, pollen, and seeds, provide important evidence of how Alaska's vegetation has responded to climate changes over time periods of centuries to millions of years. Long-term trends of global temperatures have been reconstructed from oxygen isotope measurements of microscopic fossils (foraminifera) in the Pacific Ocean (fig. 1). This temperature curve can be used to compare the major changes in Alaskan vegetation with global climate changes spanning the past 20 million years.

USGS studies of the Alaskan fossil record of plants include data from many natural exposures and sediment cores (fig. 2). These data provide the basis for reconstructing the record of past vegetation changes over millions of years of Earth history. The fossil record shows that dramatic changes in high latitude vegetation have occurred many times in the past,

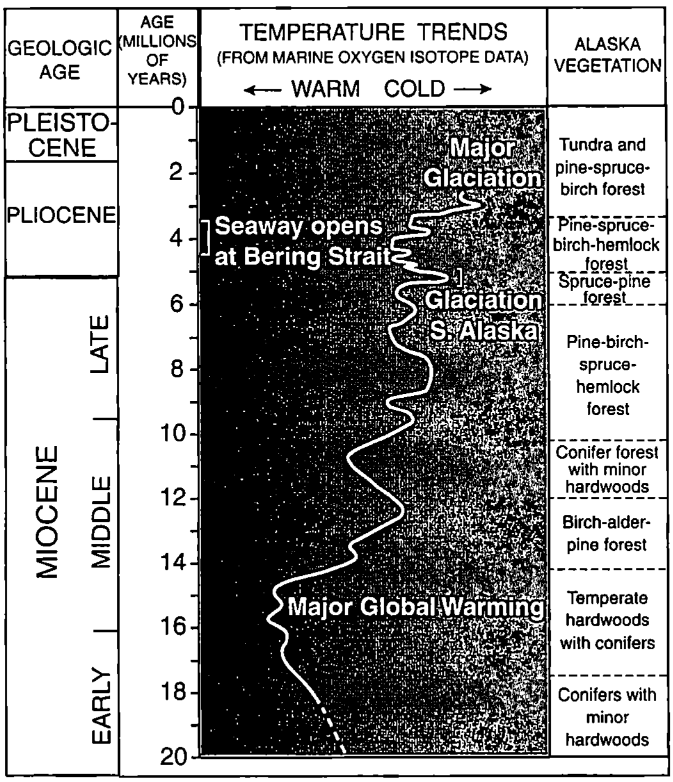

Figure 1. Pacific Ocean seawater temperature trends derived from measurements of oxygen isotopes in fossil marine organisms provide the climatic framework for interpreting the Alaskan fossil plant record.

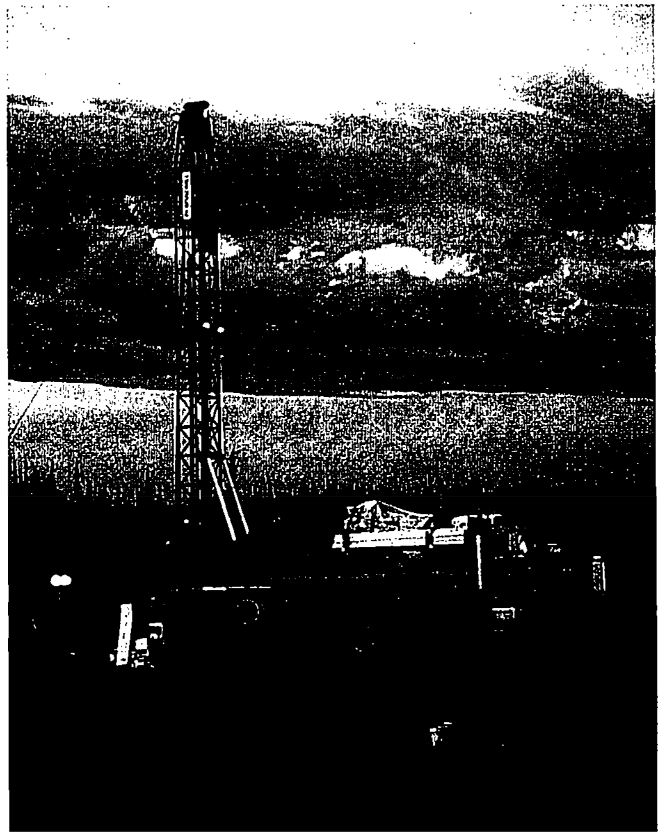

Figure 2. U.S. Geological Survey's global change drilling project at Fort Yukon, Alaska recovered a detailed record of climate and environmental change for interior Alaska spanning much of the past 16 million years.

primarily in response to global climate changes. The record further suggests that the magnitude of ecological response to global climate change is greater at high latitudes than at low latitudes. During the Miocene, a major global warming event occurred between 17 to 14.5 Ma (million years ago). In Alaska and in other high latitude regions of the world, this warming event profoundly changed vegetation from a conifer-dominated forest with few temperate hardwoods to a temperate forest containing many tree and shrub species now found far to the south in Asia and North America, such as oak, hickory, beech, chestnut, walnut, wing-nut, elm, holly, basswood, hazelnut, and sweetgum. In order for temperate vegetation to grow at such high latitudes, the mean annual temperature of interior Alaska must have been about 25-30° F warmer than today.

Global cooling began about 14.5 Ma, and its influence on Alaskan vegetation was abrupt and dramatic. Temperate trees disappeared, leaving behind a simpler forest vegetation of hardy birch, alder, and pine species until a more complex conifer-dominated forest developed after about 12 Ma. A series of cool climate pulses during the middle and late Miocene and late Pliocene eliminated additional tree species from Alaskan forests. Minor warming events about 11, 9, and 7 Ma reversed these trends slightly for brief periods, but the overall trend during the Miocene and Pliocene was the steady reduction in tree and shrub species, leaving hardy plant types that could grow in Alaska's progressively cooler climate. By the middle Pliocene, about 3 Ma, Alaskan vegetation began to resemble modern Alaskan boreal forests. Middle Pliocene forests were composed primarily of pine, spruce, larch, birch, alder, and willow, and with the exception of pine, these compose the vegetation found today in Alaska's boreal forests.

Global climate changes during the past 2.5 million years have been extreme, oscillating between relatively long periods (ca. 100,000 years) of predominantly cold, dry glacial climates and shorter intervals (ca. 10-20,000 years) of warmer, moister interglacial climates. During full glacial intervals, mean annual temperature in interior Alaska declined about 9 to 15° F below modern temperatures. During cold periods, glaciers expanded from the 5 percent of Alaska they now cover to 30 to 50 percent of the present area of the State. When glaciers expanded and temperatures declined, tundra vegetation spread to lower elevations and forests were reduced to small areas in the eastern interior, and some tree species may have been eliminated entirely from Alaska (fig. 3).

During warm interglacial periods such the one we are currently experiencing (the Holocene, spanning the past 10,000 years), boreal forests of spruce, larch, poplar, birch, alder, and willow spread throughout most of interior Alaska. During the warmest part of the previous interglacial (about 130,000 to 120,000 years ago), average growing season temperatures in Alaska appear to have been at least 5° F warmer than today. Spruce-dominated boreal forests spread north of the Brooks Range and west to the Bering Sea coast, areas where lowland tundra vegetation now grows. Warmer summer temperatures allowed trees to grow at higher altitudes than today. The expansion of forests into higher elevations greatly reduced the area covered by upland tundra communities for thousands of years.

During periods of less extreme cool climates (interstadials), Alaskan vegetation was dominated by shrub and herb-shrub tundra communities; boreal forest vegetation was restricted to a few areas in the interior lowlands of Alaska. The fossil record provides important evidence of how past climate changes influence Alaskan vegetation. Examples of both colder and warmer than modern climatic conditions of the past can be found in the geologic record, and the ecological responses to climate changes of different magnitudes can be studied. This valuable record of the past is useful for testing the results of computer simulations of climate change on global and regional scales.

Implications for future climate change

The study of past climates and ecological changes in Alaska are an important key to understanding the likely consequences of future climate changes in high latitude ecosystems. Future climate changes, whether triggered by human-induced changes in the atmosphere or by natural climate cycles will result in changes in the species composition and distribution of vegetation types. On the basis of the fossil record and climate history of Alaska, we can expect that future periods of cooler, drier climate will result in shrinkage of forest boundaries, lowering of altitudinal tree line, and expansion of tundra vegetation into lower elevations. A future change to warmer, moister climates will result in expansion of Alaska's forests into areas now occupied by tundra. The past record also shows that the magnitude of future global scale climate changes and ecological responses will be greater at high latitudes than at lower latitudes.

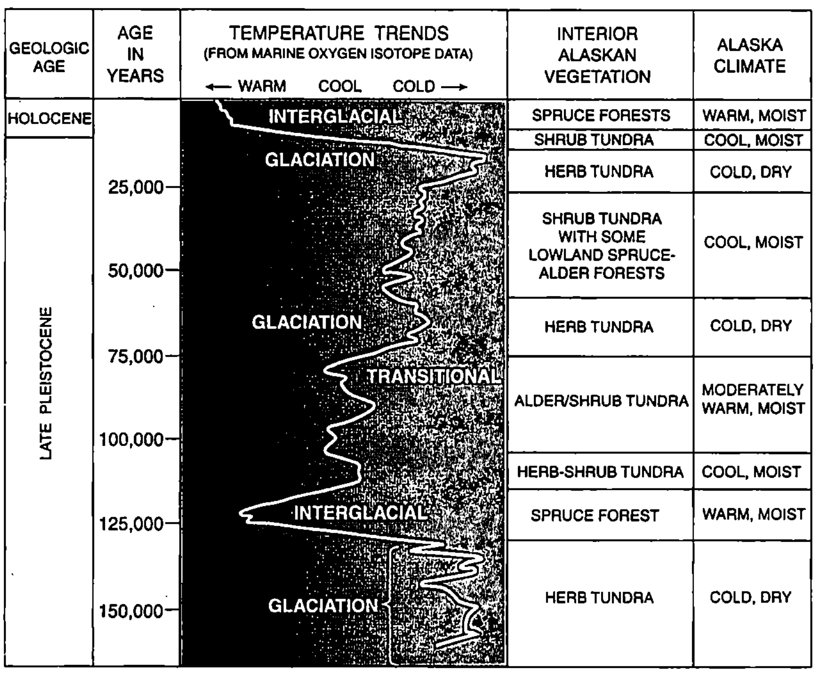

Figure 3. Global climate trends and major vegetation changes in Alaska during the last 160,000 years.

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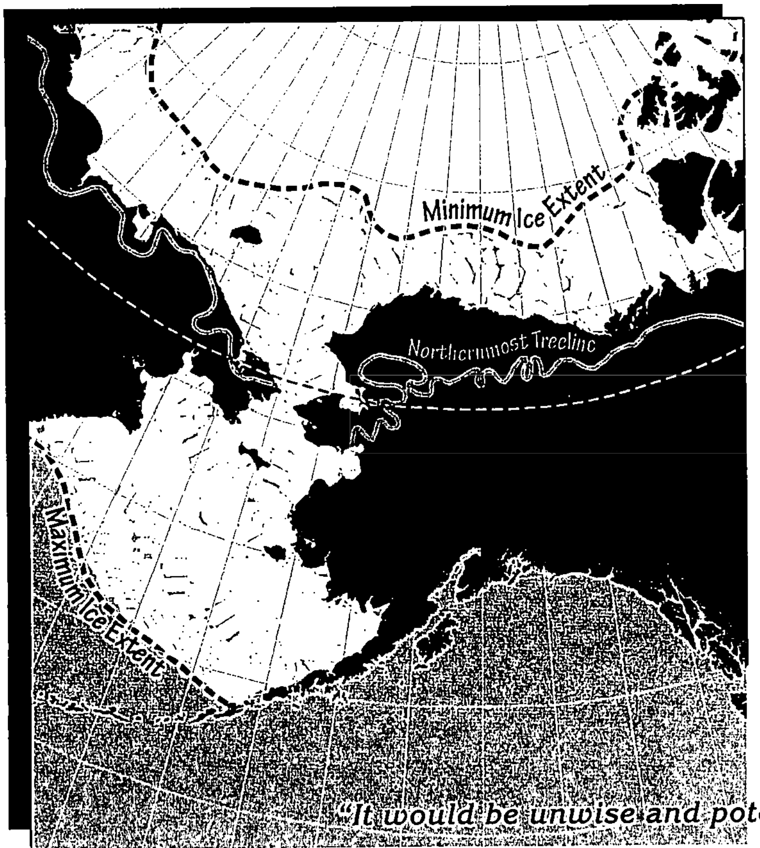
Global warming in Alaska



What is the problem?
How serious is it?
Who will be affected?
What can we do?

"It would be unwise and potentially dangerous to ignore the mounting concern (about climate change)."

John Browne
CEO, British Petroleum
May 1997

How will warmer temperatures affect Alaska?

Will changing weather affect our forests and wildlife?

Will warmer water affect our fisheries?

Will summers be drier?

Will permafrost thaw?

What can we do?

Climate change presents unique challenges. We need to develop strategies for responding to these challenges. Where do we begin? What can society and individuals do?

- ❑ Become informed about climate change, its causes and consequences.
- ❑ Apply knowledge about climate change to federal, state and local planning.
- ❑ Prepare to adapt to climate change, e.g., protect coastal areas from erosion.
- ❑ Reduce greenhouse gas emissions by:
  - *developing sound environmental policies,*
  - *using alternative energy sources, e.g., solar power,*
  - *being frugal about energy consumption.*
- ❑ Encourage support of scientific investigations on climate change.

> *"More research is needed on the detail of cause and effect, on the consequences of what appears to be happening, and on the effectiveness of the various actions which can be taken."* *John Browne*
> *CEO, British Petroleum*
> *May 1997*

We are just beginning to understand climate change and its possible consequences. Our current knowledge indicates that we cannot ignore these issues. Accurate predictions and increased effectiveness in planning will require further study.

The Assessment of the Consequences of Climate Change in Alaska and the Bering Sea region was funded by the U.S. Global Change Research Program, the National Science Foundation, the U.S. Department of the Interior, and the International Arctic Science Committee. For more information, contact the Center for Global Change and Arctic System Research at the University of Alaska Fairbanks. Phone: (907) 474-5698 FAX: (907) 474-6722 Web site: http://www.besis.uaf.edu

BESIS
Bering Sea Impacts Study

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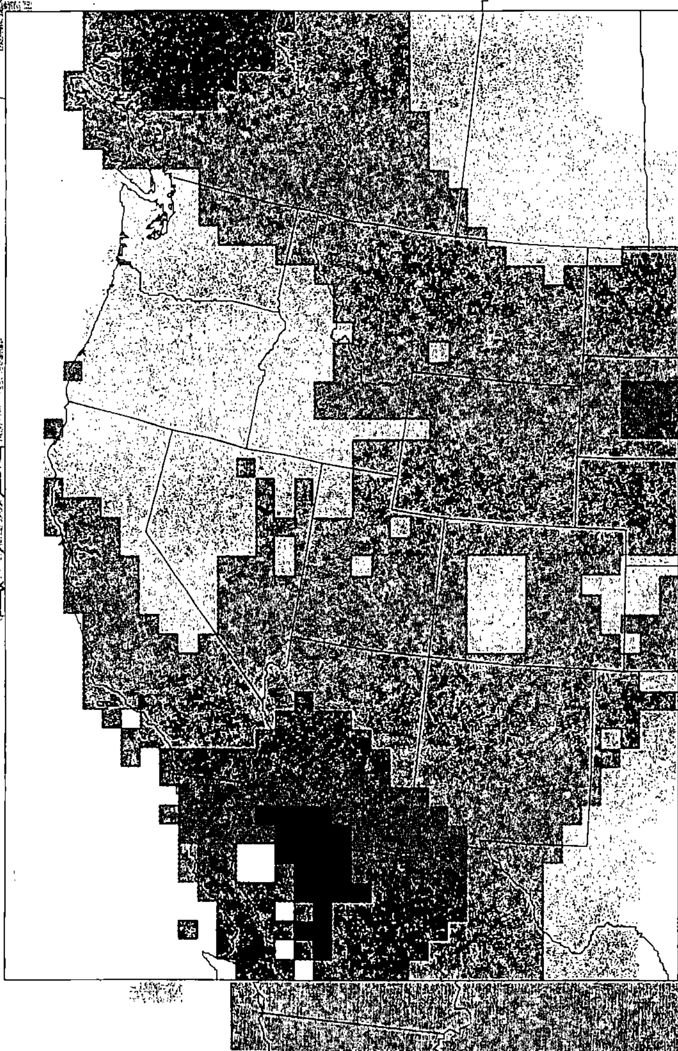
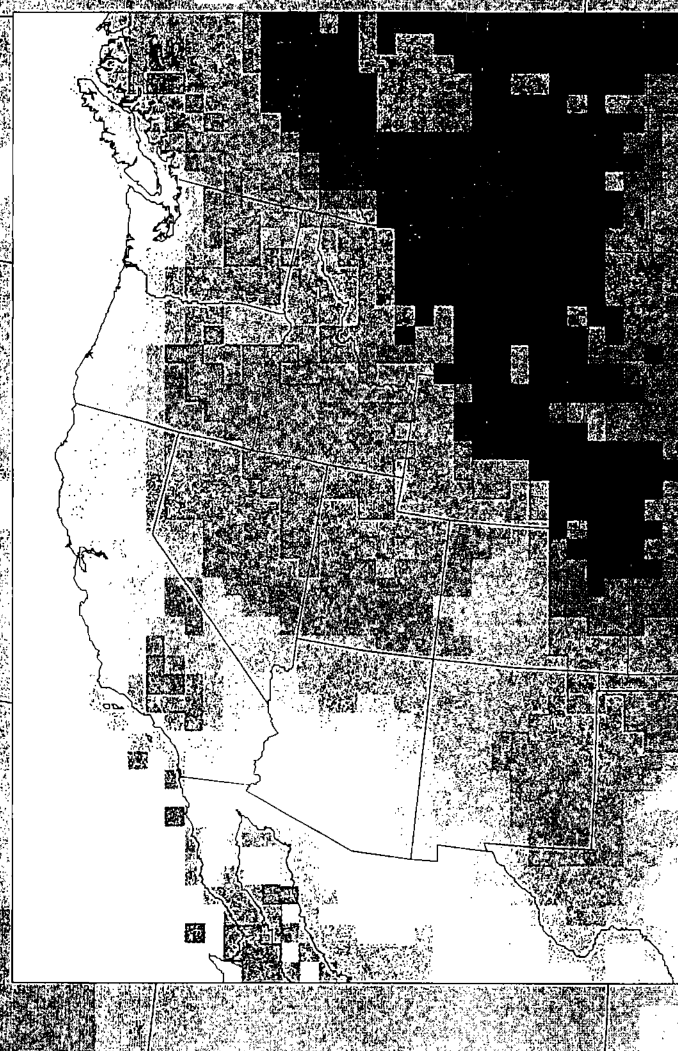
science for a changing world

A Strategy for Assessing Potential Future Changes in Climate, Hydrology, and Vegetation in the Western United States





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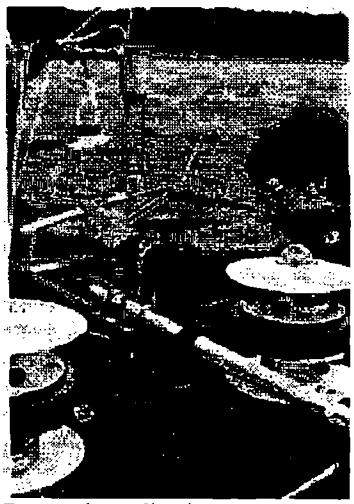
Global Change Research Program

Exchanges of Greenhouse Gases, Water Vapor, and Heat at the Earth's Surface

Atmospheric turbulence transports greenhouse gases (notably: carbon dioxide (CO_2), methane, and nitrous oxide), water vapor, and heat between Earth's land and water surfaces and the overlying atmosphere. These exchanges influence climate, viability of ecosystems, distribution of biomes, and the quantity of both surface- and ground-water. Using the eddy covariance method (explained later, below) derived from fundamental micrometeorological theory, the exchanges of greenhouse gases, water vapor, and heat may be directly measured to better understand interactions between Earth's surface and atmosphere.

Lake-atmosphere CO_2 exchange

Wind, temperature, humidity, and CO_2 concentration sensing instruments on tower in Williams Lake. Raft contains data logging and logistical support equipment.



Researcher adjusting micrometeorological instruments on tower in Williams Lake.

Although lakes occupy only a small fraction of Earth's surface area, study of the CO_2 exchange between them and the atmosphere is needed to better define the carbon cycle and to improve our understanding of air-water gas transfer over much larger water bodies such as oceans. Williams Lake (part of the USGS's Interdisciplinary Research Initiative in the Mississippi River headwaters area of north-central Minnesota) was selected for a 3 year (1992-4) study of air-water CO_2 exchange. Detailed measurements of lake-water CO_2 concentrations were made over the course of the experiment. Eddy covariance instruments were deployed from a tower that was inserted into lake sediments and guyed underwater.

A raft tethered to the tower supplied data logging and logistical support for the equipment. Eddy covariance measurements of CO_2 flux and measured change in lake CO_2 storage were compared with state of the art models of flux over water. Agreement was inconsistent between the two measurements and the models, bringing into question whether some other mechanisms, not represented in the models, were at work. The models tested are often used to estimate global air-sea CO_2 exchange. (See Anderson et al. 1999; Limnology and Oceanograph vol. 44 for further details.)

Forests: Sequestering atmospheric CO_2 and humidifying the atmosphere

Boreal forests

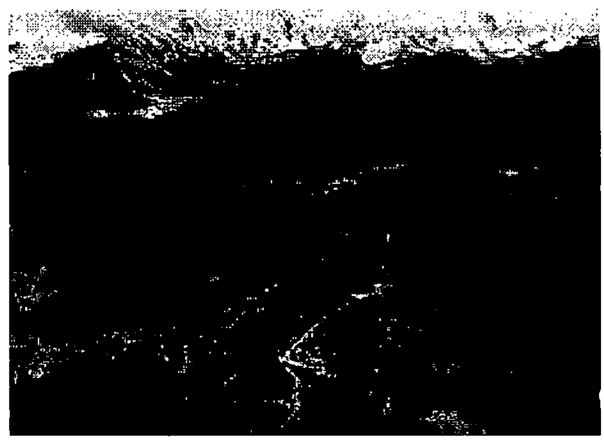

Researcher installing micrometeorological instruments on a communications-type tower in a Canadian coniferous forest.

For decades, a large number of scientists have found that after accounting for all known global carbon sinks and sources, a large unknown sink of atmospheric CO_2 seems to exist somewhere in the biosphere. BOREAS (BOReal Ecosystem Atmosphere Study) was developed and executed (1993-5) in north-central Canada to determine to what extent boreal forests may be contributing to this missing sink. A team of USGS scientists operated eddy covariance instruments deployed from a tower above a jack pine forest during BOREAS, which measured the net exchange of CO_2 and heat, and evapotranspiration (the combination of evaporated and transpired water). USGS researchers joined others from U.S. (NASA, NOAA, EPA) and Canadian (Forestry, Agriculture) governmental agencies and a variety of universities from several countries, employing a variety of measurement methodologies over the mosaic of boreal landscapes, to determine how boreal forests affect climate (through modification of atmospheric greenhouse gas concentrations, heating, humidification, and radiant energy exchange), and vice versa.

In addition to establishing that jack pine forests are a weak, perhaps ephemeral, sink for atmospheric CO_2, the USGS team found age dependent differences of carbon sequestration with younger forests drawing about 20% more CO_2 than mature stands. The USGS and other BOREAS science teams found that evapotranspiration from these forests was considerably less than originally thought while heat flux to the atmosphere was considerably more. This finding has bearing on the parameterization of these forests in numerical weather prediction models (see J. Geophys. Res. (1997), BOREAS Special Issue, Vol. 102).

U.S. Subalpine forest

Long term (years), continuous, measurements of forest ecosystem-atmosphere exchange of CO_2, evapotranspiration, and heat flux will be conducted in a subalpine forest (3048 meters (10,000 feet) MSL), near the Continental Divide, west of Boulder, CO. Though of much smaller scale, this study has similar science goals as were stated above for BOREAS. An additional goal is to improve our fundamental understanding of the character of turbulent transport of heat and gas in mountainous (complex) terrain. Presently, very little is known of forest-atmosphere exchanges of greenhouse gases, heat, and evapotranspiration from montane and subalpine forests.

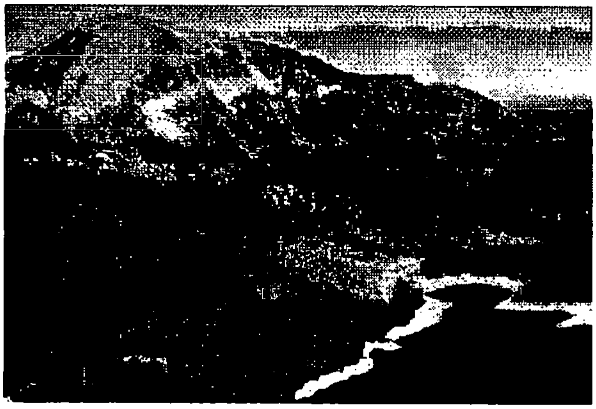


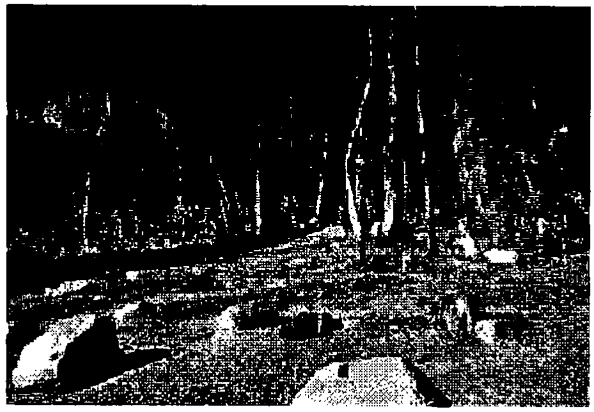
Subalpine forest site west of Boulder, Colorado. The Rocky Mountain range in the background is part of the Continental Divide.

Infrastructure is currently being emplaced near the Niwot Ridge LTER (Long term Ecological Research) site. This site operates as a part of Ameriflux -a group of individual investigators making eddy covariance measurements in North and South America (see Science (1998) Vol 281. p.506, for more information). Detailed eddy covariance flux measurements, and wind and CO_2 concentration profile measurements will be conducted from two 33 m (110') tall towers, individually operated by the University of Colorado and the USGS, in collaboration with NCAR (National Center for Atmospheric Research) researchers and with the cooperation of the U.S. Forest Service. This will be the first Ameriflux site capable of directly measuring nocturnal drainage flow of CO_2 flux originating from ecosystem respiration. CO_2 flux carried by this flow can be a substantial fraction of the total diurnal and annual forest-atmosphere flux.

CO_2 Emissions from Volcanoes

Volcanic CO_2 emissions from low-level eruptive activity can pose a threat to life in its vicinity and is a topic of interest in a range of sciences including global climate change and chemical geology. In several areas on Mammoth Mountain, a dacitic volcano on the eastern Sierras of California, soil CO_2 concentrations are in excess of 70% or 700,000 ppm (global average atmospheric concentration is about 355 ppm). Very high rates of tree mortality accompany these areas since roots require oxygen for respiration, not CO_2.

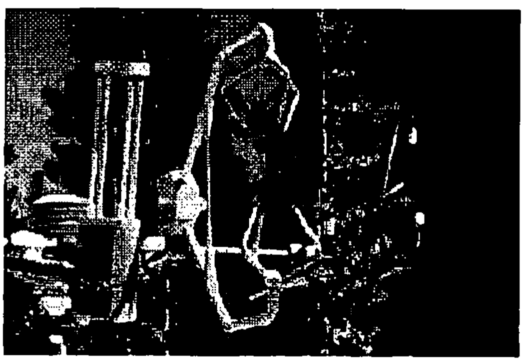

Horseshoe Lake appears in the foreground at the foot of Mammoth Mountain. The area of high CO_2 flux and tree mortality appears at the far shore of the lake.


Trees killed on Mammoth Mountain due to very high concentrations of CO_2 in soils.

In a unique application of the eddy covariance method, diffuse gas emissions from the volcano's flank were continuously measured in three pilot studies (1996,'97,'98). These week-long studies afforded the opportunity to evaluate the feasibility of this methodology in the measurement of a strong, heterogeneous, CO_2 source in complex terrain. These were the first direct measurements of CO_2 flux of volcanic origin. Results indicate that the basic assumptions underlying the eddy covariance technique were preserved in this experiment and that long term, continuous measurements may be made at the site. (Procedures and results are to appear later this year in Chemical Geology.)

Why Was the Eddy Covariance Method Chosen in the Above Studies?

A variety of micrometeorological methods and surface based chambers are available to make gas and heat flux measurements (see Anderson, D.E. 1999. Chapter 9 in Unsaturated Zone Hydrology for Scientists and Engineers (Tindall and Kunkel), Prentice Hall). Considering all methods (above), eddy covariance is the only method in which the exchanges or fluxes of gas and heat between the Earth's surface and the atmosphere may be directly measured for large areas (hectares to 100's of hectares).


Eddy covariance equipment used in some studies mentioned on this page. Left to right in foreground: CO_2 and Water Vapor sensor; Sonic anemometer capable of measuring wind velocity and temperature (center); and, Sonic anemometer (chrome color body) capable of sensing only vertical wind and temperature.

A mean flux of gas or heat may be measured with the eddy covariance method when turbulence, generated by the movement of air immediately above the Earth's surface, transports the gas or heat energy across a plane normal to the surface generating it.

Gas or heat flux is determined by calculating a covariance statistic of the fluctuations in vertical wind velocity and the entity of interest (gas concentration or temperature) from a series of sequential measurements made over time (about 30 minutes, typically). To sufficiently capture significant turbulent motions, eddy covariance instrumentation must be capable of accurately sampling wind or gas concentration at least several times per second. The instrumentation may be costly (depending upon needs) and considerable care is needed to ensure that environmental conditions will not violate assumptions underlying the methodology (see Kaimal and Finnigan, 1994, Atmospheric

Boundary Layer Flows, Oxford Press, N.Y.). Instruments are typically deployed from fixed platforms (e.g. towers or scaffolding) meters to 10's of meters above the surface. Depending upon instrument height above the surface, eddy covariance measurements are representative of a surface-atmosphere flux occurring over an upwind area on the order of hectares to 100's of hectares. Usually the higher the instruments are placed, the larger the upwind area sampled. In some instances, eddy covariance instruments have been flown aboard aircraft, enabling researchers to make comparative flux measurements over 100's of kilometers.

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