EXECUTIVE SUMMARY

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1 INTRODUCTION AND BACKGROUND

This report is an assessment of the effects of climate change on U.S. land resources, water resources, agriculture, and biodiversity. It is one of a series of 21 Synthesis and Assessment Products being produced under the auspices of the U.S. Climate Change Science Program (CCSP), which coordinates the climate change research activities of U.S. government agencies. The lead sponsor of this particular assessment product is the U.S. Department of Agriculture (USDA). The project was led and coordinated by the National Center for Atmospheric Research (NCAR).

This assessment is based on extensive review of the relevant scientific literature and measurements and data collected and published by U.S. government agencies. The team of authors includes experts in the fields of agriculture, biodiversity, and land and water resources – scientists and researchers from universities, national laboratories, non-government organizations, and government agencies. To generate this assessment of the effects of climate and climate change, the authors conducted an exhaustive review, analysis, and synthesis of the scientific literature, considering more than 1,000 separate publications.

Scope

The CCSP agencies agreed on the following set of topics for this assessment. Descriptions of the major findings in each of these sectors can be found in Section 4 of this Executive Summary.

- Agriculture: (a) cropping systems, (b) pasture and grazing lands, and (c) animal management
- Land Resources: (a) forests and (b) arid lands
- Water Resources: (a) quantity, availability, and accessibility and (b) quality
- Biodiversity: (a) species diversity and (b) rare and sensitive ecosystems

The CCSP also agreed on a set of questions to guide the assessment process. Answers to these questions can be found in Section 3 of this summary:

- What factors influencing agriculture, land resources, water resources, and biodiversity in the United States are sensitive to climate and climate change?
- How could changes in climate exacerbate or ameliorate stresses on agriculture, land resources, water resources, and biodiversity? What are the indicators of these stresses?
- What current and potential observation systems could be used to monitor these indicators?
- Can observation systems detect changes in agriculture, land resources, water resources, and biodiversity that are caused by climate change, as opposed to being driven by other causes?

Our charge from the CCSP was to address the specific topics and questions from the prospectus. This had several important consequences for this report. We were asked not to make recommendations and we have adhered to this request. Our document is not a plan for scientific or agency action, but rather an assessment and analysis of current scientific understanding of the topics defined by the CCSP. In addition, we were asked not to define and examine options for adapting to climate change impacts. This topic is addressed in a separate CCSP Synthesis and Assessment Product. Our authors view adaptation as a very important issue and recognize that adaptation options will certainly affect the ultimate severity of many climate change impacts. Our findings and conclusions are relevant to informed assessment of adaptation options, but we have not attempted that task in this report.

Time Horizon

Many studies of climate change have focused on the next 100 years. Model projections out to 2100 have become the de facto standard, as in the assessment reports produced by the Intergovernmental Panel on Climate Change (IPCC). This report has benefited greatly from such literature, but our main focus is on the recent past and the nearer-term future – the next 25 to 50 years. This period is within the planning horizon of many natural resources managers. Furthermore, the climate change that will occur during this period is relatively well understood. Much of this change will be caused by greenhouse gas emissions that have already happened. It is thus partially independent of current or planned emissions control measures and the large scenario uncertainty that affects longer-term projections. We report some results out to 100 years to frame our assessment, but we emphasize the coming decades.

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Ascribing Confidence to Findings

The authors have endeavored to use consistent terms, agreed to by the CCSP agencies, to describe their confidence in the findings and conclusions in this report, particularly when these involve projections of future conditions and accumulation of information from multiple sources. The use of these terms represents the judgment of the authors of this document; much of the underlying literature does not use such a lexicon and we have not retroactively applied this terminology to previous studies by other authors.

Climate Context

There is a robust scientific consensus that human-induced climate change is occurring. The Fourth Assessment Report (AR4) of the IPCC, the most comprehensive and up-to-date scientific assessment of this issue, states with "very high confidence" that human activities, such as fossil fuel burning and deforestation, have altered the global climate. During the 20th century, the global average surface temperature increased by about 0.6°C and global sea level increased by about 15 to 20 cm. Global precipitation over land increased about two percent during this same period. Looking ahead, human influences will continue to change Earth's climate throughout the 21st century. The IPCC AR4 projects that the global average temperature will rise another 1.1 to 5.4°C by 2100, depending on how much the atmospheric concentrations of greenhouse gases increase during this time. This temperature rise will result in continued increases in sea level and overall rainfall, changes in rainfall patterns and timing, and decline in snow cover, land ice, and sea ice extent. It is very likely that the Earth will experience a faster rate of climate change in the 21st century than seen in the last 10,000 years.

The United States warmed and became wetter overall during the 20th century, with changes varying by region. Parts of the South have cooled, while northern regions have warmed – Alaskan temperatures have increased by 2 to 4°C (more than four times the global average). Much of the eastern and southern United States now receive more precipitation than 100 years ago, while other areas, especially in the Southwest, receive less. The frequency and duration of heat waves has increased, there have been large declines in summer sea ice in the Arctic, and there is some evidence of increased frequency of heavy rainfalls. Observational and modeling results documented in the IPCC AR4 indicate that these trends are very likely to continue. Temperatures in the United States are very likely to increase by another 1ºC to more than 4ºC. The West and Southwest are likely to become drier, while the eastern United States is likely to experience increased rainfall. Heat waves are very likely to be hotter, longer, and more frequent, and heavy rainfall is likely to become more frequent.

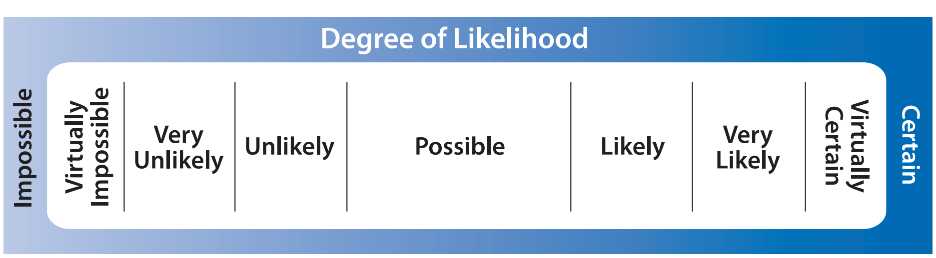

Figure 1 Language for Describing Confidence in Findings

2 OVERARCHING CONCLUSIONS

Climate changes – temperature increases, increasing CO_2 levels, and altered patterns of precipitation – are already affecting U.S. water resources, agriculture, land resources, and biodiversity *(very likely)*. The literature reviewed for this assessment documents many examples of changes in these resources that are the direct result of variability and changes in the climate system, even after accounting for other factors. The number and frequency of forest fires and insect outbreaks are increasing in the interior West, the Southwest, and Alaska. Precipitation, streamflow, and stream temperatures are increasing in most of the continental United States. The western United States is experiencing reduced snowpack and earlier peaks in spring runoff. The growth of many crops and weeds is being stimulated. Migration of plant and animal species is changing the composition and structure of arid, polar, aquatic, coastal, and other ecosystems.

Climate change will continue to have significant effects on these resources over the next few decades and beyond *(very likely)*. Warming is very likely to continue in the United States during the next 25 to 50 years, regardless of reductions in greenhouse gas emissions, due to emissions that have already occurred. U.S. ecosystems and natural resources are already being affected by climate system changes and variability. It is very likely that the magnitude and frequency of ecosystem changes will continue to increase during this period, and it is possible that they will accelerate. As temperature rises, crops will increasingly experience temperatures above the optimum for their reproductive development, and animal production of meat or dairy products will be impacted by temperature extremes. Management of Western reservoir systems is very likely to become more challenging as runoff patterns continue to change. Arid areas are very likely to experience increases erosion and fire risk. In arid ecosystems that have not coevolved with a fire cycle, the probability of loss of iconic, charismatic megaflora such as Saguaro cacti and Joshua trees will greatly increase.

Many other stresses and disturbances are also affecting these resources *(very likely)*. For many of the changes documented in this assessment, there are multiple environmental drivers – land use change, nitrogen cycle changes, point and nonpoint source pollution, wildfires, invasive species – that are also changing. Atmospheric deposition of biologically available nitrogen compounds continues to be an important issue, along with persistent ozone pollution in many parts of the country. It is very likely that these additional atmospheric effects cause biological and ecological changes that interact with changes in the physical climate system. In addition, land cover and land use patterns are changing, e.g., the increasing fragmentation of U.S. forests as exurban development spreads to previously undeveloped areas, further raising fire risk and compounding the effects of summer drought, pests, and warmer winters. There are several dramatic examples of extensive spread of invasive species throughout rangeland and semiarid ecosystems in western states, and indeed throughout the United States. It is likely that the spread of these invasive species, which often change ecosystem processes, will exacerbate the risks from climate change alone. For example, in some cases invasive species increase fire risk and decrease forage quality.

Climate change impacts on ecosystems will affect the services that ecosystems provide, such as cleaning water and removing carbon from the atmosphere *(very likely)*, but we do not yet possess sufficient understanding to project the timing, magnitude, and consequences of many of these effects. One of the main reasons to assess changes in ecosystems is to understand the consequences of those changes for the delivery of services that our society values. There are many analyses of the impacts of climate change on individual species and ecosystems in the scientific literature, but there is not yet adequate integrated analysis of how climate change could affect ecosystem services. A comprehensive understanding of impacts on these services will only be possible through quantification of anticipated alterations in ecosystem function and productivity. As described by the Millennium Ecosystem Assessment, some products of ecosystems, such as food and fiber, are priced and traded in markets.

Climate changes – temperature increases, increasing CO_2 levels, and altered patterns of precipitation – are already affecting U.S. water resources, agriculture, land resources, and biodiversity.

Others, such as carbon sequestration capacity, are only beginning to be understood and traded in markets. Still others, such as the regulation of water quality and quantity and the maintenance of soil fertility, while not priced and traded, are valuable nonetheless. Although these points are recognized and accepted in the scientific literature and increasingly among decision makers, there is no analysis specifically devoted to understanding changes in ecosystem services in the United States from climate change and associated stresses. It is possible to make some generalizations from the literature on the physical changes in ecosystems, but interpreting what these changes mean for services provided by ecosystems is very challenging and can only be done for a limited number of cases. This is a significant gap in our knowledge base.

Existing monitoring systems, while useful for many purposes, are not optimized for detecting the impacts of climate change on ecosystems. There are many operational and research monitoring systems in the United States that are useful for studying the consequences of climate change on ecosystems and natural resources. These range from the resource- and species-specific monitoring systems that land-management agencies depend on to research networks, such as the Long-Term Ecological Research (LTER) sites, which the scientific community uses to understand ecosystem processes. All of the existing monitoring systems, however, have been put in place for other reasons, and none have been optimized specifically for detecting the effects and consequences of climate change. As a result, it is likely that only the largest and most visible consequences of climate change are being detected. In some cases, marginal changes and improvements to existing observing efforts, such as USDA snow and soil moisture measurement programs, could provide valuable new data detection of climate impacts. But more refined analysis and/or monitoring systems designed specifically for detecting climate change effects would provide more detailed and complete information and probably capture a range of more subtle impacts. Such systems, in turn, might lead to early-warning systems and more accurate forecasts of potential future changes. But it must be emphasized that improved observations, while needed, are not sufficient for improving understanding of ecological impacts of climate change. Ongoing, integrated and systematic analysis of existing and new observations could enable forecasting of ecological change, thus garnering greater value from observational activities, and contribute to more effective evaluation of measurement needs. This issue is addressed in greater detail in Section 3.

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3 KEY QUESTIONS AND ANSWERS

This section presents a set of answers to the guiding questions posed by the CCSP agencies, derived from the longer chapters that follow this Executive Summary.

What factors influencing agriculture, land resources, water resources, and biodiversity in the United States are sensitive to climate and climate change? Climate change affects average temperatures and temperature extremes; timing and geographical patterns of precipitation; snowmelt, runoff, evaporation, and soil moisture; the frequency of disturbances, such as drought, insect and disease outbreaks, severe storms, and forest fires; atmospheric composition and air quality; and patterns of human settlement and land use change. Thus, climate change leads to myriad direct and indirect effects on U.S. ecosystems. Warming temperatures have led to effects as diverse as altered timing of bird migrations, increased evaporation, and longer growing seasons for wild and domestic plant species. Increased temperatures often lead to a complex mix of effects. Warmer summer temperatures in the western United States have led to longer forest growing seasons but have also increased summer drought stress, vulnerability to insect pests, and fire hazard. Changes to precipitation and the size of storms affect plant-available moisture, snowpack and snowmelt, streamflow, flood hazard, and water quality.

How could changes in climate exacerbate or ameliorate stresses on agriculture, land resources, water resources, and biodiversity? What are the indicators of these stresses? Ecosystems and their services (land and water resources, agriculture, biodiversity) experience a wide range of stresses, including pests and pathogens, invasive species, air pollution, extreme events, wildfires and floods. Climate change can cause or exacerbate direct stress through high temperatures, reduced water availability, and altered frequency of extreme events and severe storms. It can ameliorate stress through warmer springs and longer growing seasons, which, assuming adequate moisture, can increase agricultural and forest productivity. Climate change can also modify the frequency and severity of stresses. For example, increased minimum temperatures and warmer springs extend the range and lifetime of many pests that stress trees and crops. Higher temperatures and/or decreased precipitation increase drought stress on wild and crop plants, animals and humans. Reduced water availability can lead to increased withdrawals from rivers, reservoirs, and groundwater, with consequent effects on water quality, stream ecosystems, and human health.

What current and potential observation systems could be used to monitor these indicators? A wide range of observing systems within the United States provides information on environmental stress and ecological responses. Key systems include National Aeronautics and Space Administration (NASA) research satellites, operational satellites and ground-based observing networks from the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce, Department of Agriculture (USDA) forest and agricultural survey and inventory systems, Department of Interior/U.S. Geological Survey (USGS) stream gauge networks, Environmental Protection Agency (EPA) and state-supported water quality observing systems, the Department of Energy (DOE) Ameriflux network, and the LTER network and the proposed National Ecological Observing Network (NEON) sponsored by the National Science Foundation (NSF). However, many key biological and physical indicators are not currently monitored, are monitored haphazardly or with incomplete spatial coverage, or are monitored only in some regions. In addition, the information from these disparate networks is not well integrated. Almost all of the networks were originally instituted for specific purposes unrelated to climate change and cannot necessarily be adapted to address these new questions.

Climate change presents new challenges for operational management. Understanding climate impacts requires monitoring both many aspects of climate and a wide range of biological and physical responses. Putting climate change impacts in the context of multiple stresses and forecasting future services requires an integrated analysis. Beyond the problems of integrating the data sets, the nation has limited operational capability for integrated ecological monitoring, analyses, and forecasting. A few centers exist, aimed at specific questions and/or regions, but no coordinating agency or center has the mission to conduct integrated environmental analysis and assessment by pulling this information together.

Warming temperatures have led to effects as diverse as altered timing of bird migrations, increased evaporation, and longer growing seasons for wild and domestic plant species.

Operational weather and climate forecasting provides an analogy. Weather-relevant observations are collected in many ways, ranging from surface observations through radiosondes to operational and research satellites. These data are used at a handful of university, federal, and private centers as the basis for analysis, understanding, and forecasting of weather through highly integrative analyses blending data and models. This operational activity requires substantial infrastructure and depends on federal, university, and private sector research for continual improvement. By contrast, no such integrative analysis of comprehensive ecological information is carried out, although the scientific understanding and societal needs have probably reached the level where an integrative and operational approach is both feasible and desirable.

Can observation systems detect changes in agriculture, land resources, water resources, and biodiversity that are caused by climate change, as opposed to being driven by other causes? In general, the current suite of observing systems is reasonably able overall to monitor ecosystem change and health in the United States, but neither the observing systems nor the current state of scientific understanding is adequate to rigorously quantify climate contributions to ecological change and separate these from other influences. Monitoring systems for measuring long-term response of **agriculture** to climate and other stresses are numerous, but integration across these systems is limited. There is no coordinated national network for monitoring changes in **land resources** associated with climate change, most disturbances, such as storms, insects, and diseases, and changes in land cover/land use. No aspect of the current hydrologic observing system was designed specifically to detect climate change or its effects on **water resources**. The monitoring systems that have been used to evaluate the relationship between changes in the physical climate system and **biological diversity** were likewise not designed with climate variability or change in mind.

Climate change is likely to lead to a northern migration of weeds.

So for the moment, there is no viable alternative to using the existing systems for identifying climate change and its impacts on U.S. agriculture, land resources, water resources, and biodiversity, even though these systems were not originally designed for this purpose. There has obviously been some considerable success so far in doing so, but there is limited confidence that the existing systems provide a true early warning system capable of identifying potential impacts in advance. The authors of this report also have very limited confidence in the ability of current observation and monitoring systems to provide the information needed to evaluate the effectiveness of actions that are taken to mitigate or adapt to climate change impacts. Furthermore, we emphasize that improvements in observations and monitoring of ecosystems, while desirable, are not sufficient by themselves for increasing our understanding of climate change impacts. Experiments that directly manipulate climate and observe impacts are critical for developing more detailed information on the interactions of climate and ecosystems, attributing impacts to climate, differentiating climate impacts from other stresses, and designing and evaluating response strategies. Much of our understanding of the direct effects of temperature, elevated CO_2, ozone, precipitation, and nitrogen deposition has come from manipulative experiments. Institutional support for such experiments is a concern.

4 SECTORAL FINDINGS

Agriculture

The broad subtopics considered in this section are cropping systems, pasture and grazing lands, and animal management. The many U.S. crops and livestock varieties (valued at about $200 billion in 2002) are grown in diverse climates, regions, and soils. No matter the region, however, weather and climate factors such as temperature, precipitation, CO_2 concentrations, and water availability directly impact the health and well-being of plants, pasture, rangeland, and livestock. For any agricultural commodity, variation in yield between years is related to growing-season weather; weather also influences insects, disease, and weeds, which in turn affect agricultural production.

- With increased CO_2 and temperature, the life cycle of grain and oilseed crops will likely progress more rapidly. But, as temperature rises, these crops will increasingly begin to experience failure, especially if climate variability increases and precipitation lessens or becomes more variable.

- The marketable yield of many horticultural crops – e.g., tomatoes, onions, fruits – is very likely to be more sensitive to climate change than grain and oilseed crops.

- Climate change is likely to lead to a northern migration of weeds. Many weeds respond more positively to increasing CO_2 than most cash crops, particularly C3 "invasive" weeds. Recent research also suggests that glyphosate, the most widely used herbicide in the United States, loses its efficacy on weeds grown at the increased CO_2 levels likely in the coming decades.

- Disease pressure on crops and domestic animals will likely increase with earlier springs and warmer winters, which will allow proliferation and higher survival rates of pathogens and parasites. Regional variation in warming and changes in rainfall will also affect spatial and temporal distribution of disease.

- Projected increases in temperature and a lengthening of the growing season will likely extend forage production into late fall and early spring, thereby decreasing need for winter season forage reserves. However, these benefits will very likely be affected by regional variations in water availability.

- Climate change-induced shifts in plant species are already under way in rangelands. Establishment of perennial herbaceous species is reducing soil water availability early in the growing season. Shifts in plant productivity and type will likely also have significant impact on livestock operations.

- Higher temperatures will very likely reduce livestock production during the summer season, but these losses will very likely be partially offset by warmer temperatures during the winter season. For ruminants, current management systems generally do not provide shelter to buffer the adverse effects of changing climate; such protection is more frequently available for non-ruminants (e.g., swine and poultry).

- Monitoring systems for measuring long-term response of agricultural lands are numerous, but integration across these systems is limited. Existing state-and-transition models could be expanded to incorporate knowledge of how agricultural lands and products respond to global change; integration of such models with existing monitoring efforts and plant developmental data bases could provide cost-effective strategies that both enhance knowledge of regional climate change impacts and offer ecosystem management options. In addition, at present, there are no easy and reliable means to accurately ascertain the mineral and carbon state of agricultural lands, particularly over large areas; a fairly low-cost method of monitoring biogeochemical response to global change would be to sample ecologically important target species in different ecosystems.

Land Resources

The broad subtopics considered in this section are forest lands and arid lands. Climate strongly influences forest productivity, species composition, and the frequency and magnitude of disturbances that impact forests. The effect of climate change on disturbances such as forest fire, insect outbreaks, storms, and severe drought will command public attention and place increasing demands on management resources. Disturbance and land use will control the response of arid lands to climate change. Many plants and animals in arid ecosystems are near their physiological limits for tolerating temperature and water stress and even slight changes in stress will have significant consequences. In the near term, fire effects will trump climate effects on ecosystem structure and function.

- Climate change has very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior West, the Southwest, and Alaska, and will continue to do so.

- Rising CO_2 will very likely increase photosynthesis for forests, but this increase will likely only enhance wood production in young forests on fertile soils.

Climate change has very likely increased the size and number of forest fires, insect outbreaks, and tree mortality in the interior West, the Southwest, and Alaska, and will continue to do so.

- Nitrogen deposition and warmer temperatures have very likely increased forest growth where adequate water is available and will continue to do so in the near future.

- The combined effects of rising temperatures and CO_2, nitrogen deposition, ozone, and forest disturbance on soil processes and soil carbon storage remains unclear.

- Higher temperatures, increased drought, and more intense thunderstorms will very likely increase erosion and promote invasion of exotic grass species in arid lands.

- Climate change in arid lands will create physical conditions conducive to wildfire, and the proliferation of exotic grasses will provide fuel, thus causing fire frequencies to increase in a self-reinforcing fashion.

Stream temperatures are likely to increase as the climate warms, and are very likely to have both direct and indirect effects on aquatic ecosystems.

- In arid regions where ecosystems have not coevolved with a fire cycle, the probability of loss of iconic, charismatic megaflora such as saguaro cacti and Joshua trees is very likely.

- Arid lands very likely do not have a large capacity to absorb CO_2 from the atmosphere and will likely lose carbon as climate-induced disturbance increases.

- River and riparian ecosystems in arid lands will very likely be negatively impacted by decreased streamflow, increased water removal, and greater competition from non-native species.

- Changes in temperature and precipitation will very likely decrease the cover of vegetation that protects the ground surface from wind and water erosion.

- Current observing systems do not easily lend themselves to monitoring change associated with disturbance and alteration of land cover and land use, and distinguishing such changes from those driven by climate change. Adequately distinguishing climate change influences is aided by the collection of data at certain spatial and temporal resolutions, as well as supporting ground truth measurements.

Water Resources

The broad subtopics considered in this section are water quantity and water quality. Plants, animals, natural and managed ecosystems, and human settlements are susceptible to variations in the storage, fluxes, and quality of water, all of which are sensitive to climate change. The effects of climate on the nation's water storage capabilities and hydrologic functions will have significant implications for water management and planning as variability in natural processes increases. Although U.S. water management practices are generally quite advanced, particularly in the West, the reliance on past conditions as the foundation for current and future planning and practice will no longer be tenable as climate change and variability increasingly create conditions well outside of historical parameters and erode predictability.

- Most of the United States experienced increases in precipitation and streamflow and decreases in drought during the second half of the 20th century. It is likely that these trends are due to a combination of decadal-scale variability and long-term change.

- Consistent with streamflow and precipitation observations, most of the continental United States experienced reductions in drought severity and duration over the 20th century. However, there is some indication of increased drought severity and duration in the western and southwestern United States.

- There is a trend toward reduced mountain snowpack and earlier spring snowmelt runoff peaks across much of the western United States. This trend is very likely attributable at least in part to long-term warming, although some part may have been played by decadal-scale variability, including a shift in the phase of the Pacific Decadal Oscillation in the late 1970s. Where earlier snowmelt peaks and reduced summer and fall low flows have already been detected, continuing shifts in this direction are very likely and may have substantial impacts on the performance of reservoir systems.

- Water quality is sensitive to both increased water temperatures and changes in precipitation. However, most water quality changes observed so far across the continental United States are likely attributable to causes other than climate change.

- Stream temperatures are likely to increase as the climate warms, and are very likely to have both direct and indirect effects on aquatic ecosystems. Changes in temperature will be most evident during low flow periods, when they are of greatest concern. Stream temperature increases have already begun to be detected across some of the United States, although a comprehensive analysis similar to those reviewed for streamflow trends has yet to be conducted.

- A suite of climate simulations conducted for the IPCC AR4 show that the United States may experience increased runoff in eastern regions, gradually transitioning to little change in the Missouri and lower Mississippi, to substantial decreases in annual runoff in the interior of the west (Colorado and Great Basin).

- Trends toward increased water use efficiency are likely to continue in the coming decades. Pressures for reallocation of water will be greatest in areas of highest population growth, such as the Southwest. Declining per capita (and, for some cases, total) water consumption will help mitigate the impacts of climate change on water resources.

- Essentially no aspect of the current hydrologic observing system was designed specifically to detect climate change or its effects on water resources. Recent efforts have the potential to make improvements, although many systems remain technologically obsolete, incompatible, and/or have significant data collection gaps in their operational and maintenance structures. As a result, many of the data are fragmented, poorly integrated, and unable to meet the predictive challenges of a rapidly changing climate.

Biodiversity

The broad subtopics considered in this section are species diversity and rare and sensitive ecosystems. Biodiversity, the variation of life at the genetic, species, and ecosystem levels of biological organization, is the fundamental building block of the services that ecosystems deliver to human societies. It is intrinsically important both because of its contribution to the functioning of ecosystems, and because it is difficult or impossible to recover or replace, once it is eroded. Climate change is affecting U.S. biodiversity and ecosystems, including changes in growing season, phenology, primary production, and species distributions and diversity. It is very likely that climate change will increase in importance as a driver for changes in biodiversity over the next several decades, although for most ecosystems it is not currently the largest driver of change.

- There has been a significant lengthening of the growing season and increase in net primary productivity (NPP) in the higher latitudes of North America. Over the last 19 years, global satellite data indicate an earlier onset of spring across the temperate latitudes by 10 to 14 days.

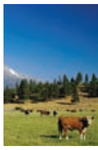
- In an analysis of 866 peer-reviewed papers exploring the ecological consequences of climate change, nearly 60 percent of the 1598 species studied exhibited shifts in their distributions and/or phenologies over the 20- and 140-year time frame. Analyses of field-based phenological responses have reported shifts as great as 5.1 days per decade, with an average of 2.3 days per decade across all species.

- Subtropical and tropical corals in shallow waters have already suffered major bleaching events that are clearly driven by increases in sea surface temperatures. Increases in ocean acidity, which are a direct consequence of increases in atmospheric carbon dioxide, are calculated to have the potential for serious negative consequences for corals.

- The rapid rates of warming in the Arctic observed in recent decades, and projected for at least the next century, are dramatically reducing the snow and ice covers that provide denning and foraging habitat for polar bears.

- There are other possible, and even probable, impacts and changes in biodiversity (e.g., disruption of the relationships between pollinators, such as bees, and flowering plants), for which we do not yet have a substantial observational database. However, we cannot conclude that the lack of complete observations is evidence that changes are not occurring.

- It is difficult to pinpoint changes in ecosystem services that are specifically related to changes in biological diversity in the United States. A specific assessment of changes in ecosystem services for the United States as a consequence of changes in climate or other drivers of change has not been done.



It is also not clear that existing networks can be maintained for long enough to enable careful time-series studies to be conducted.

- The monitoring systems that have been used to evaluate the relationship between changes in the physical climate system and biological diversity have three components: species-specific or ecosystem-specific monitoring systems, research activities specifically designed to create time-series of population data and associated climatic and other environmental data, and spatially extensive observations derived from remotely sensed data. However, in very few cases were these monitoring systems established with climate variability and climate change in mind, so the information that can be derived from them specifically for climate-change-related studies is somewhat limited. It is also not clear that existing networks can be maintained for long enough to enable careful time-series studies to be conducted.