Ecosystems

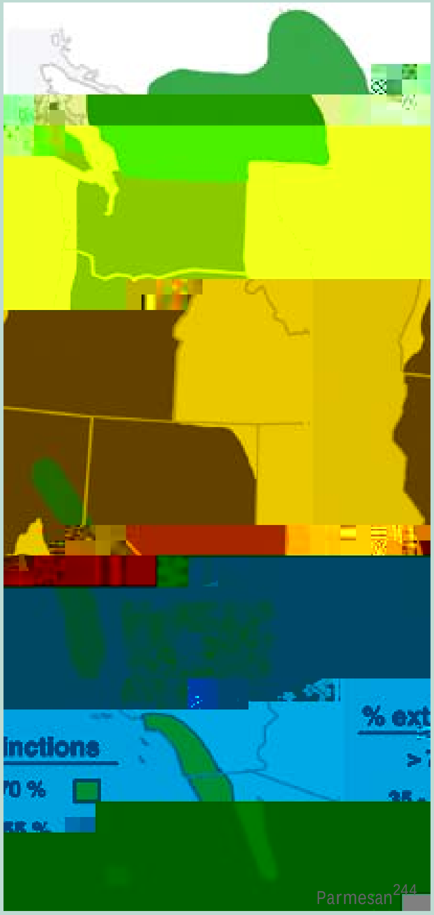
Key Messages:

- Ecosystem processes, such as those that control growth and decomposition, have been affected by climate change.
- Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue.
- Fires, insect pests, disease pathogens, and invasive weed species have increased, and these trends are likely to continue.
- Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fre, and erosion.
- Coastal and near-shore ecosystems are already under multiple stresses. Climate change and ocean acidifcation will exacerbate these stresses.
- Arctic sea ice ecosystems are already being adversely affected by the loss of summer sea ice and further changes are expected.
- The habitats of some mountain species and coldwater fsh, such as salmon and trout, are very likely to contract in response to warming.
- Some of the benefts ecosystems provide to society will be threatened by climate change, while others will be enhanced.

The natural functioning of the environment provides both goods – such as food and other products that are bought and sold – and services, which our society depends upon. For example, ecosystems store large amounts of carbon in plants and soils; they regulate water flow and water quality; and they stabilize local climates. These services are not assigned a financial value, but society nonetheless depends on them. Ecosystem processes are the underpinning of these services: photosynthesis, the process by which plants capture carbon dioxide from the atmosphere and create new growth; the plant and soil processes that recycle nutrients from decomposing matter and maintain soil fertility; and the processes by which plants draw water from soils and return water to the atmosphere. These ecosystem processes are affected by climate and by the concentration of carbon dioxide in the atmosphere.[70]

The diversity of living things (biodiversity) in ecosystems is itself an important resource that maintains the ability of these systems to provide the [illegible]

Butterfly Range Shifts Northward



As climate warms, many species in the United States are shifting their ranges northward and to higher elevations. The map shows the response of Edith's checkerspot butterfly populations to a warming climate over the past 136 years in the American West. Over 70 percent of the southernmost populations (shown in yellow) have gone extinct. The northernmost populations and those above 8,000 feet elevation in the cooler climate of California's Sierra Nevada (shown in green) are still thriving. These differences in numbers of population extinctions across the geographic range of the butterfly have resulted in the average location shifting northward and to higher elevations over the past century, illustrating how climate change is altering the ranges of many species. Because their change in range is slow, most species are not expected to be able to keep up with the rapid climate change projected in the coming decades.[244]

A higher atmospheric carbon dioxide concentration causes trees and other plants to capture more carbon from the atmosphere, but experiments show that trees put much of this extra carbon into producing fine roots and twigs, rather than new wood. The effect of carbon dioxide in increasing growth thus seems to be relatively modest, and generally is seen most strongly in young forests on fertile soils where there is also sufficient water to sustain this growth. In the future, as atmospheric carbon dioxide continues to rise, and as climate continues to change, forest growth in some regions is projected to increase, especially in relatively young forests on fertile soils.[243]

Forest productivity is thus projected to increase in much of the East, while it is projected to decrease in much of the West where water is scarce and projected to become more so. Wherever droughts increase, forest productivity will decrease and tree death will increase. In addition to occurring in much of the West, these conditions are projected to occur in parts of Alaska and in the eastern part of the Southeast.[243]

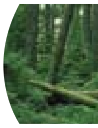
Large-scale shifts have occurred in the ranges of species and the timing of the seasons and animal migration, and are very likely to continue.

Climate change is already having impacts on animal and plant species throughout the United States. Some of the most obvious changes are related to the timing of the seasons: when plants bud in spring, when birds and other animals migrate, and so on. In the United States, spring now arrives an average of 10 days to two weeks earlier than it did 20 years ago. The growing season is lengthening over much of the continental United States. Many migratory bird species are arriving earlier. For example, a study of northeastern birds that migrate long distances found that birds wintering in the southern United States now arrive back in the Northeast an average of 13 days earlier than they did during the first half of the last century. Birds wintering in South America arrive back in the Northeast an average of four days earlier.[70]

Another major change is in the geographic distribution of species. The ranges of many species in the United States have shifted northward and upward in elevation. For example, the ranges of many butterfly species have expanded northward, contracted at the southern edge, and shifted to higher elevations as warming has continued. A study of Edith's checkerspot butterfly showed that 40 percent of the populations below 2,400 feet have gone extinct, despite the availability of otherwise suitable habitat and food supply. The checkerspot's most southern populations also have gone extinct, while new populations have been established north of the previous northern boundary for the species.[70]

For butterflies, birds, and other species, one of the concerns with such changes in geographic range and timing of migration is the potential for mismatches between species and the resources they need to survive. The rapidly changing landscape, such as new highways and expanding urban areas, can create barriers that limit habitat and increase species loss. Failure of synchronicity between butterflies and the resources they depend upon has led to local population extinctions of the checkerspot butterfly during extreme drought and low-snowpack years in California.[70]

Forest tree species also are expected to shift their ranges northward and upslope in response to climate change, although specific quantitative predic-



ture, however, since it is one of the environmental stresses on species and ecosystems that is continuing to increase.[247] The Intergovernmental Panel on Climate Change has estimated that if a warming of 3.5 to 5.5°F occurs, 20 to 30 percent of species that conditions which are thought to have enabled the proliferation of an amphibian disease.[70,251]

Diseases that affect wildlife and the living things that carry these diseases have been expanding their geographic ranges as climate heats up. Depending on their specific adaptations to current climate, many parasites, and the insects, spiders, and scorpions that carry and transmit diseases, die or fail to develop below threshold temperatures. Therefore, as temperatures rise, more of these disease-carrying creatures survive. For some species, rates of reproduction, population growth, and biting, tend to increase with increasing temperatures, up to a limit. Some parasites' development rates and infectivity periods also increase with temperature.[70] An analysis of diseases among marine species found that diseases were increasing for mammals, corals, turtles, and mollusks, while no trends were detected for sharks, rays, crabs, and shrimp.[70]

Problems involving invasive plant species arise from a mix of human-induced changes, including disturbance of the land surface (such as through over grazing or clearing natural vegetation for development), deliberate or accidental transport of non-native species, the increase in available nitrogen through over-fertilization of crops, and the rising carbon dioxide concentration and the resulting climate change.[243] Human-induced climate change is not generally the initiating factor, nor the most important one, but it is becoming a more important part of the mix.

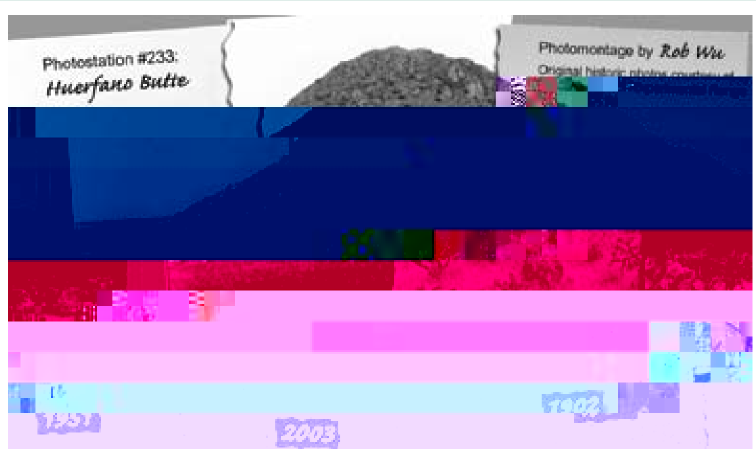
The increasing carbon dioxide concentration stimulates the growth of most plant species, and some invasive plants respond with greater growth rates than native plants. Beyond this, invasive plants appear to better tolerate a wider range of environmental conditions and may be more successful in a warming world because they can migrate and establish themselves in new sites more rapidly than native plants.[70] They are also not usually dependent on external pollinators or seed dispersers to reproduce. For all of these reasons, invasive plant species present a growing problem that is extremely difficult to control once unleashed.[70]

Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion.

The arid Southwest is projected to become even drier in this century. There is emerging evidence that this is already underway.[34] Deserts in the United States are also projected to expand to the north, east, and upward in elevation in response to projected warming and associated changes in climate.

Increased drying in the region contributes to a variety of changes that exacerbate a cycle of desertification. Increased drought conditions cause perennial plants to die due to water stress and increased susceptibility to plant diseases. At the same time, non-native grasses have invaded the region. As these grasses increase in abundance, they provide more fuel for fires, causing fire frequency to increase in a self-reinforcing cycle that leads to further losses of vegetation. When it does rain, the rain tends to come in heavy downpours, and since there is less vegetation to protect the soil, water erosion increases. Higher air temperatures and decreased soil moisture reduce soil stability, further exacerbating erosion. And with a growing population needing water for urban uses, hydroelectric generation, and agriculture, there is increasing pressure on mountain water sources that would otherwise flow to desert river areas.[70,149]

Desertification of Arid Grassland
near Tucson, Arizona, 1902 to 2003



CCSP SAP 4.3[243]

The photo series shows the progression from arid grassland to desert (desertification) over a 100-year period. The change is the result of grazing management and reduced rainfall in the Southwest.[250,252,253]

But rising temperature is not the only stress coral reefs face. As the carbon dioxide concentration in the air increases, more carbon dioxide is absorbed into the world's oceans, leading to their acidification. This makes less calcium carbonate available for corals and other sea life to build their skeletons and shells.[258] If carbon dioxide concentrations continue to rise and the resulting acidification proceeds, eventually, corals and other ocean life that rely on calcium carbonate will not be able to build these skeletons and shells at all. The implications of such extreme changes in ocean ecosystems are not clear, but there is now evidence that in some ocean areas, such as along the Northwest coast, acidification is already occurring[70,259] (see *Coasts* region for more discussion of ocean acidification).

Arctic sea ice ecosystems are already being adversely affected by the loss of summer sea ice and further changes are expected.

Perhaps most vulnerable of all to the impacts of warming are Arctic ecosystems that rely on sea ice, which is vanishing rapidly and is projected to disappear entirely in summertime within this century. Algae that bloom on the underside of the sea ice form the base of a food web linking microscopic animals and fish to seals, whales, polar bears, and people. As the sea ice disappears, so too do these algae. The ice also provides a vital platform for ice-dependent seals (such as the ringed seal) to give birth, nurse their pups, and rest. Polar bears use the ice as a platform from which to hunt their prey. The walrus rests on the ice near the continental shelf between its dives to eat clams and other shellfish. As the ice edge retreats away from the shelves to deeper areas, there will be no clams nearby.[70,132,220]

The Bering Sea, off the west coast of Alaska,

wahacopic
2(e)TJ0 (e)2(b a)-117r nsk l

growing;[266] the jobs created by recreational tourism provide economic benefits not only to individuals but also to communities. Slightly more than 90 percent of the U.S. population participates in some form of outdoor recreation, representing nearly 270 million participants,[267] and several billion days spent each year in a wide variety of outdoor recreation activities.

Since much recreation and tourism occurs outside, increased temperature and precipitation have a direct effect on the enjoyment of these activities, and on the desired number of visitor days and associated level of visitor spending as well as tourism employment. Weather conditions are an important factor influencing tourism visits. In addition, outdoor recreation and tourism often depends on the availability and quality of natural resources,[268] such as beaches, forests, wetlands, snow, and wildlife, all of which will be affected by climate change.

Thus, climate change can have direct effects on the natural resources that people enjoy. The length of the season for, and desirability of, several of the most popular activities – walking; visiting a beach, lakeshore, or river; sightseeing; swimming; and picnicking[267] – are likely to be enhanced by small near-term increases in temperature. Other activities are likely to be harmed by even small increases in warming, such as snow- and ice-dependent activities including skiing, snowmobiling, and ice fishing.

The net economic effect of near-term climate change on recreational activities is likely to be positive. In the longer term, however, as climate change effects on ecosystems and seasonality become more pronounced, the net economic effect on tourism and recreation is not known with certainty.[172]

Adaptation: Preserving Coastal Wetlands

Coastal wetlands are rich ecosystems that protect the shore from damage during storm surges and provide society with other services. One strategy designed to preserve coastal wetlands as sea level rises is the “rolling easement.” Rolling easements allow some development near the shore, but prohibit construction of seawalls or other armoring to protect buildings; they recognize nature’s right-of-way to advance inland as sea level rises. Massachusetts and Rhode Island prohibit shoreline armoring along the shores of some estuaries so that ecosystems can migrate inland, and several states limit armoring along ocean shores.[269,270]

In the case shown here, the coastal marsh would reach the footprint of the house 40 years in the future. Because the house is on pilings, it could still be occupied if it is connected to a community sewage treatment system; a septic system would probably fail due to proximity to the water table. After 80 years, the marsh would have taken over the yard, and the footprint of the house would extend onto public property. The house could still be occupied but reinvestment in the property would be unlikely. After 100 years, this house would be removed, although some other houses in the area could still be occupied. Eventually, the entire area would return to nature. A home with a rolling easement would depreciate in value rather than appreciate like other coastal real estate. But if the loss were expected to occur 100 years from now, it would only reduce the current property value by 1 to 5