Natural Environment and Biodiversity

- **Ecosystem processes have been affected by climate change.**
- **There have been large-scale shifts in species ranges, the timing of the seasons, and animal migration; further such changes are projected.**
- **There have been increases in fire, insect pests, disease pathogens, and invasive weed species; more such increases are projected.**
- **Coastal and near-coastal ecosystems, including wetlands and coral reefs, are especially vulnerable to the impacts of climate change.**
- **Mountain species and cold-water fish such as salmon and trout are particularly sensitive to climate change impacts.**
- **Arctic sea-ice ecosystems are extremely vulnerable to warming.**

In addition to food, fiber, and other goods that are bought and sold in economic markets, the natural functioning of the environment provides many services on which our society depends. For example, natural ecosystems store carbon in living tissues and in soils, they regulate water flow and water quality, and they stabilize local climates, among many other services. 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.

The diversity of living things, or biodiversity, in ecosystems is itself an enormously important resource that maintains the ability of these systems to provide the services upon which we depend. Many factors affect biodiversity, including: climatic conditions; the presence of competitors, predators, parasites, and disease; disturbance from fire; and other physical factors. Human-induced climate change, in conjunction with other stresses, is beginning to exert major influences on natural environments and biodiversity, and these influences are generally expected to grow with increased warming.

Ecosystem processes have been affected by climate change.

Climate has a strong influence on the processes that control growth and development in natural ecosystems. Examples include how fast plants grow, how rapidly the cycling of nutrients occurs, and whether the carbon captured from the atmosphere and used for plant growth exceeds or is lower than the amount that is released to the atmosphere. Several trends are already evident in natural ecosystems on land in the United States. The growing season is lengthening as a consequence of higher temperatures occurring earlier in the spring. Forest growth has risen over the past several decades as a consequence of a number of factors – young forests reaching maturity, increased concentrations of carbon dioxide in the atmosphere, a longer growing season, increased deposition of nitrogen from the atmosphere – whose individual effects are difficult to disentangle.

At the same time, there have been increases in the size, frequency, and intensity of disturbances – fire and insect infestations being the most visible – that are clearly responding to changes in climate as one of several causal factors. There have also been episodes of extensive death of trees in response to continued extreme drought, especially in the already arid Southwest. There is clear evidence from observations in many different forests that long-term reductions in water availability can increase tree death as well as change the types of species that are able to survive in currently forested areas of the country.

While higher carbon dioxide (CO_2) concentrations cause trees to capture more carbon from the atmosphere, it turns out that they use very little of this extra carbon to produce new wood. The growth effect of extra CO_2 is thus relatively modest, and generally is seen most strongly in young forests on already fertile soils (with enough nitrogen available to enable more growth to occur), and where there is also sufficient water to sustain this growth.

Thus, in the future, as atmospheric CO_2 continues to rise, and as climate continues to change, some forest growth is projected to increase, but only in relatively young forests on fertile soils. The combined effects of increased temperature, increased CO_2, nitrogen deposition, and surface ozone pollution are very difficult to disentangle without substantially more experimentation and improvements in ecosystem models.

There have been large-scale shifts in species ranges, the timing of the seasons, and animal migration; further such changes are projected.

Animal and plant habitats are changing

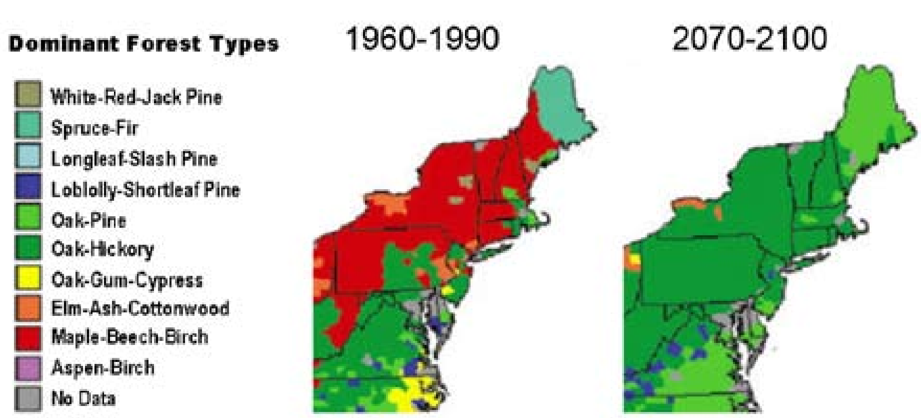
Climate change is already having impacts on animal and plant species throughout the United States. Some of the most obvious changes are related to the timing of the seasons: when plants bud in spring, when birds and other animals migrate, and so on. In the United States, spring now arrives an average of ten 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 bird species that are long-distance migrants found that birds wintering in the southern United States now arrive back in the Northeast an average of 13 days earlier than during the first half of the last century, while birds wintering in South America arrive an average of four days earlier[1].

Another major change is in the geographic distribution of species. Many species in the United States have shifted their ranges northward and upward in elevation. For example, many butterfly species have expanded their ranges northward, contracted the southern parts of their ranges, and shifted to higher elevations as warming has proceeded. A study of Edith's Checkerspot Butterfly showed that 40 percent of the populations below 2400 feet have gone extinct, despite the availability of suitable habitat and food supply. The Checkerspot's most southern populations have also gone extinct, while new populations have been established north of the previous northern boundary for the species[2].

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. Add to that the rapidly changing landscape (for example, if a species tries to shift northward with the changing climate but there's now a highway or a shopping mall on their new desirable location) and the potential for losses grows. Failure of synchronicity between butterflies and the resources they need led to population extinctions of the Checkerspot Butterfly during extreme drought and low-snowpack years in California.

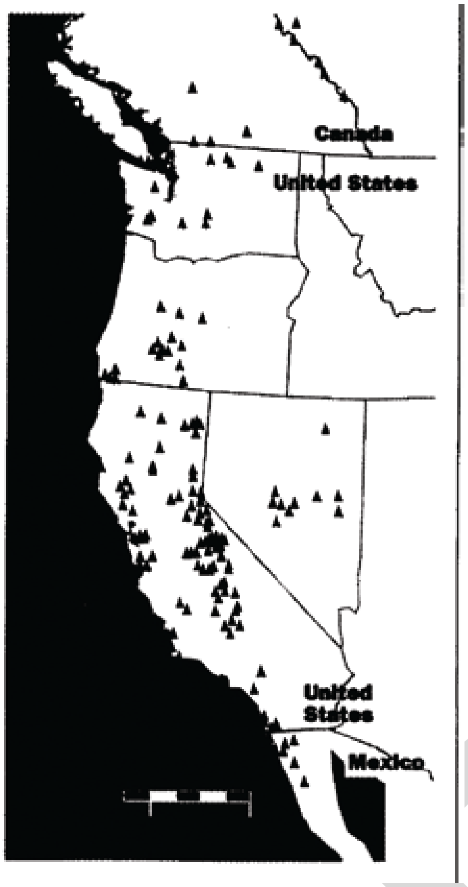
Tree species are also expected to shift their ranges northward and upslope in response to climate change, although specific quantitative predictions are very difficult to make because of the complications of human land use and many other factors. This would result in major changes in the character of U.S. forests and the types of forests that will be most prevalent in different regions. In the United States, some common forests types are projected to expand, such as oak-hickory. Others are projected to contract, such as maple-beech-birch. Still others, such as spruce-fir, are likely to disappear from the United States altogether[3].

In Alaska, vegetation changes are already underway due to warming. The treeline is shifting northward into tundra, encroaching on the habitat for many migratory birds and land animals like caribou that depend on the open tundra landscape.



The maps show current and projected forests types for the Northeast. Note that Maple-Beech-Birch, currently a dominant forest type in the region, could be completely displaced by other forest types in a warmer future[1].

As warming drives changes in timing and geographic ranges for various species, it is important to note that entire communities of species do not shift intact. Rather, the range and timing of each species shifts in response to its sensitivity to climate change, its mobility, its lifespan, and the availability of the resources it needs (like soil, moisture, food, and shelter). The ranges of animals can generally shift much faster than those of plants, and large migratory animals can move faster than small ones. In addition, migratory pathways must be available, such as northward flowing rivers as conduits for fish. Some migratory pathways may be blocked by development. All of these variations result in the break-up of existing ecosystems and formation of new ones, with unknown consequences[4].



Point to add: since climate change is happening so fast, mobile species may not able to move fast enough, and sedentary species (like trees) may not shift their ranges fast enough.

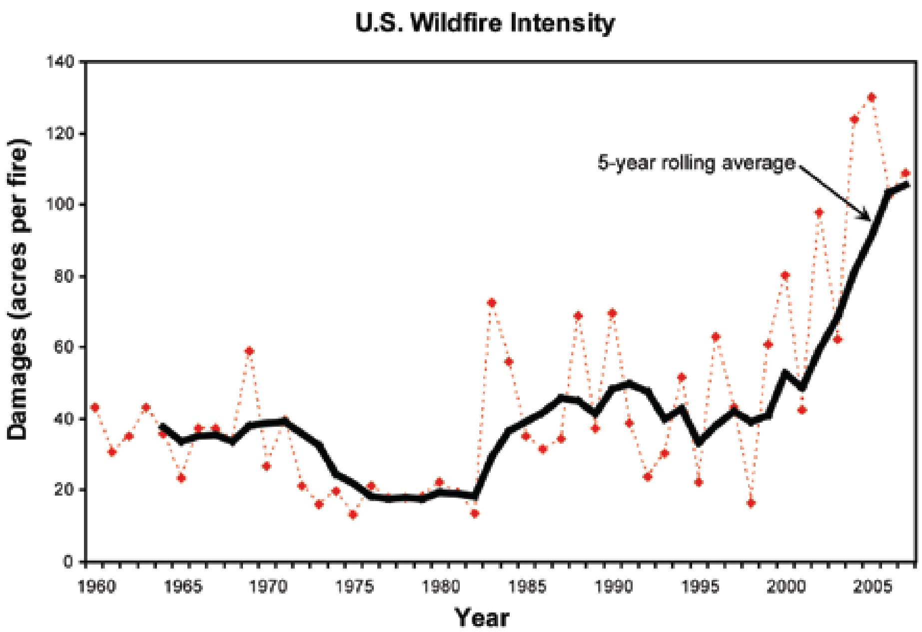
Figure source: Camille Parmesan

High resolution figure requested

There have been increases in fire, insect pests, disease pathogens, and invasive weed species, and more are projected.

Increases in frequency, intensity, and size of forest fires

In the western United States, especially in mid-elevation forests in the northern Rocky Mountains and Sierra Nevada, there have been significant increases in the frequency of large wildfires and in the length of the fire season. These changes are closely linked to earlier melting of snow in the spring, as well as increases in spring and summer temperatures. The earlier snowmelt extends the time during which ignitions can occur and contributes to drier conditions in mid-summer, leading to drier vegetation and potential fuel for fires. There is thus a clear linkage between changes in climate and the increase in fire frequency and severity.



Similar phenomena are occurring in northern forests across the continent, from Alaska through Canada. The area burned by wildfire has more than doubled between the decades of the 1960s and 1970s and the decades of the 1980s and 1990s. Both the size of fires and the number of fires due to lightning strikes appear to be correlated closely with the increase in burned area. Increased summer air temperatures are a key factor in this increase in fires in the northern forests, for much the same reasons as the changes in snowpack and temperatures in the mountain West.

Increase in insect pests

Insect pests are economically important stresses on forest ecosystems in the United States. Coupled with pathogens, they cost more than $1 billion annually in damages. Forest insect pests are well known to be sensitive to climatic variations in many stages of their life cycles. Changes in climate have contributed significantly to several major insect pest outbreaks in the United States and Canada over the past several decades. Mountain pine bark beetle in British Columbia attacking lodgepole pine is the largest of these: over 33 million acres of forest have been affected, by far the largest such outbreak in recorded history. Another 620,000 acres have been affected by pine bark beetle in Colorado. Spruce bark beetle has affected more than 2.5 million acres in Alaska and western Canada. The combination of drought and high temperatures has also led to serious insect infestations and death of pinyon pine in the Southwest, and to various insect pest attacks throughout the forests of the eastern United States.

In each case, there is an interaction of heat and drought, which tends to weaken trees' resistance to attack. There is also often a direct effect of higher temperatures on the insects themselves, such as warmer winters allowing survival of larvae through the coldest part of the year and generally higher temperatures accelerating the pests' life cycles and thus increasing their populations.

Disease pathogens and their carriers

Golden Toad, Costa Rica, now extinct

One consequence of a longer, warmer growing season and less extreme cold in winter is that opportunities are created for many insect pests and disease pathogens to flourish. Accumulating evidence links the spread of disease pathogens to a warming climate. For example, a recent study showed that widespread amphibian extinctions in the mountains of Costa Rica are linked to changes in climatic conditions[5].

A survey of recent scientific studies finds that diseases and the creatures that carry them have been expanding their geographic ranges as climate heats up. The findings confirm that, 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, can increase with increasing temperatures (up to a limit). Some parasites' development rates and infectivity periods also increase with temperature[6].

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[7].

Invasive plants

Problems involving invasive plant species arise from a mix of human-induced changes, including disturbance of the land surface (such as through grazing or development), deliberate or accidental transport of non-native species, the increase in available nitrogen, and rising carbon dioxide levels and the resulting climate change. Human-induced climate change is not generally the initiating factor, nor the most important one, but it is increasingly part of the mix.

Kudzu, Chattanooga, Tennessee

Kudzu and other invasive weed species, along with native weeds and vines, disproportionately benefit from increased carbon dioxide compared to other native plants.

Increasing carbon dioxide levels stimulate the growth of most plant species, and some invasive plants are expected to respond with greater growth rates than non-invasive plants[4]. 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[8]. 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.

Coastal and near-coastal ecosystems including wetlands and coral reefs are especially vulnerable to the impacts of climate change.

Coastal and near-shore marine ecosystems are vulnerable to a host of climate change related effects including increasing air and water temperatures, ocean acidification, changes in runoff from the land, sea-level rise, and altered currents. These changes have led to coral bleaching and diseases, shifts in species ranges, increased storm intensity in some regions, dramatic reductions in sea-ice extent and thickness along the Alaskan coast, and other significant changes to the nation's coastlines and marine ecosystems.

Coral Reefs

Coral reefs are very diverse ecosystems that support many other species by providing food and habitat. In addition to their ecological value, coral reefs provide billions of dollars in services including tourism, fish breeding habitat, and protection of coastlines. Human-induced carbon dioxide emissions and warming are causing changes that have enormous detrimental effects on coral reefs including rising water temperatures, ocean acidification, and increasing tropical storm intensity to some regions. In addition, corals face a host of other challenges related to human activities such as tourism, fishing, pollution, and development.

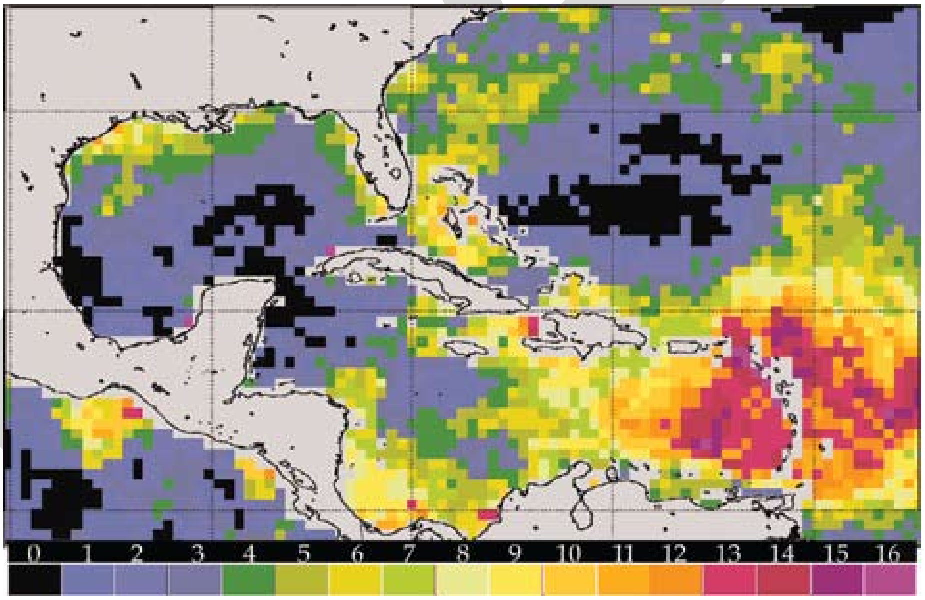
Corals are marine animals that host symbiotic algae that help nourish and give them their color. When corals are stressed by increases in water temperatures or ultraviolet light, they lose their algae and turn white, a process called coral bleaching. If the stress persists, the coral die. Intensities and frequencies of bleaching events clearly driven by warming in surface water have increased substantially over the past 30 years, leading to the death or severe damage of about a third of the world's corals[9].

The United States has extensive coral reef ecosystems in the Caribbean, Atlantic, and Pacific Oceans. In 2005, the Caribbean basin experienced unprecedented water temperatures and resulting dramatic coral bleaching with some sites in the U.S. Virgin Islands seeing 90 percent of the coral bleached. Some corals began to recover when water temperatures decreased, but later that year disease appeared, striking the previously bleached and weakened coral. To date, 50 percent of the corals in Virgin Island National Park have died from the bleaching and disease events. In the Florida Keys, summer 2005 bleaching was also followed by disease in September[10].

Projections based on temperature increases alone suggest that within the next several decades, 60 percent of the world's corals are likely to be severely damaged or destroyed. But rising temperature is not the only stress coral reefs face. As carbon dioxide concentrations in the air increase, 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. If carbon dioxide concentrations continue to rise and the resulting acidification proceeds, eventually, they will not be able to build these skeletons and shells at all. The combination of rising ocean temperatures, increasing ocean acidity, changes in light as sea level rises, increased storm intensity, and the other stresses could take coral reef ecosystems past a critical threshold for survival within decades. The loss of coral reefs would reverberate through the entire marine food web and ecosystem[10a].

Marine Fish

The distribution of marine fish and plankton are predominantly determined by climate so it is not surprising that marine species in U.S. waters are moving northward and that the timing of plankton blooms is shifting. Extensive shifts in the ranges and distributions of both warm- and cold-water species of fish have been documented in Europe and the North Atlantic, as well as in the oceans surrounding North America. In the Pacific, climate change is expected to cause an eastward shift in the location of tuna stocks[10b]. It is clear that such shifts are related to climate, including natural modes of climate variability such as El Niño-La Niña cycles. However, it is unclear how these modes of ocean variability will change as global climate continues to change, and therefore it is very difficult to predict quantitatively how marine fish and plankton species' distributions might change as a function of climate change[10a].



A measure of heat stress (NOAA's Coral Reef Watch Degree Heating Weeks) for 12 weeks before October 28, 2005 in the Caribbean Basin with the highest thermal stress ever recorded. Numbers greater than 4 indicate that some coral bleaching is expected, whereas numbers greater than 8 indicate that mass bleaching and mortality are expected.

Mountain species and cold-water fishes like salmon and trout are particularly sensitive to climate change impacts.

Mountain species

Animal and plant species that live in the mountains are among those particularly sensitive to rapid climate change. They include animal species such as the grizzly bear, bighorn sheep, pika, mountain goat, and wolverine. Major changes have already been observed in the pika as previously reported populations have disappeared entirely as climate has warmed over recent decades[11]. One reason mountain species are so vulnerable is that their suitable habitats are being compressed as climatic zones shift upward in elevation. Some species try to shift uphill with the changing climate but there may be other constraints related to food, other species present, and other variables. In addition, as species move up the mountains, those near the top simply run out of habitat.

A recent study found that fewer wild flowers are projected to grace the slopes of the Rocky Mountains as global warming causes earlier spring snowmelt. Larkspur, Aspen Fleabane, and Aspen Sunflower grow at an altitude of about 9500 feet where the winter snows are deep. Once the snow melts, the flowers form buds and prepare to bloom. But warmer springs mean that the snow has been melting earlier, leaving the buds exposed to frost (the percentage of buds that were frosted has doubled over the past decade). Frost doesn't kill the plants but does make them unable to seed and reproduce, meaning there will be no next generation. Insects and other animal species depend on the flowers for food, and other species depend on those species, so the loss is likely to propagate through the food chain[12].

Pika

Shifts in tree species on mountains in New England, where temperatures have risen 2 to 4°F in the last 40 years, offer another example. Some mountain tree species have shifted uphill by 350 feet in the last 40 years – a rate much faster than expected. Tree communities were relatively unchanged at low and high elevations, but in the transition zone in between, at about 2600 feet elevation, the changes have been dramatic. Cold-loving tree species declined from 43 to 18 percent while warmer-loving trees increase from 57 to 82 percent. Overall, the transition zone shifted about 350 feet uphill in just a few decades, a surprisingly rapid rate since these are trees that live for hundreds of years. One possibility is that as trees were damaged or killed by air pollution, it left an opportunity for the warming-induced transition to occur more quickly. These results indicate that high-elevation forests may be jeopardized by climate change sooner than anticipated[13].

Illustration of species shifting upslope
under development

Cold-water fish

Salmon and other cold-water fish species in the United States are at particular risk from warming. Salmon are under threat from a variety of human activities, notably dams in the Northwest, but global warming is a growing source of stress. Dams often restrict salmon to lower and warmer elevations. Rising temperatures impact salmon in several important ways. As precipitation increasingly falls as rain rather than snow, it feeds floods that wash away salmon eggs incubating in the streambed. Warmer water leads eggs to hatch earlier in the year, so the young are smaller and more vulnerable to predators. Warmer conditions increase the fish's metabolism, taking energy away from growth and forcing the fish to find more food, but earlier hatching of eggs could put them out of sync with the insects they eat. Earlier melting of snow leaves rivers and streams warmer and shallower in summer and fall. Diseases and parasites tend to flourish in warmer water. Studies suggest that up to 40 percent of Northwest salmon populations may be lost by 2050[14].

Large declines in trout populations are also projected to occur around the United States. Over half of the wild trout populations will likely disappear from the southern Appalachian Mountains because of the effects of warming stream temperatures. Losses of western trout populations may exceed 60 percent in certain regions. About 90 percent of bull trout, which live in western rivers in some of the country's most wild places, may be lost due to warming. Pennsylvania is predicted to lose 50 percent of its trout habitat in the coming decades. Other states such as North Carolina and Virginia could lose up to 90 percent of their trout habitat due to warming[15].

Salmon returning up stream to spawn at Willow Creek, Oregon.

Arctic sea ice ecosystems are extremely vulnerable to warming.

Arctic wildlife

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 leading through zooplankton 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 (like 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[16].

Placeholder box for figure under development

[graphics: illustration of sea ice ecosystem]]

The Bering Sea off the west coast of Alaska produces our nation's largest commercial fish harvests as well as providing food for many Native Alaskans. Ultimately, the fish populations (and those of seabirds, seals, walruses, whales, etc.) depend on plankton blooms regulated by the extent and location of the ice edge in spring. As the sea ice continues to decline, the location, timing, and species make-up of the blooms is changing. The spring melt of sea ice in the Bering Sea has long provided material that feeds the clams, shrimp and other life forms on the ocean floor that in turn provide food for the walruses, gray whales, bearded seals, eider ducks, and many fish. The earlier ice melt resulting from warming, however, leads to later phytoplankton blooms that are largely consumed by zooplankton near the sea surface, vastly decreasing the amount of food reaching the living things on the ocean floor. This will radically change the make-up of the fish and other creatures, with significant repercussions for commercial and subsistence fishing[17].

Ringed seals give birth in snow caves on the sea ice, which protect the pups from extreme cold and predators. Warming leads to earlier snow melt which causes the snow caves to collapse before the pups are weaned. The small exposed pups may die of hypothermia or be vulnerable to predation by arctic foxes, polar bears, gulls, and ravens. Gulls and ravens are arriving in the Arctic earlier as springs become warmer, increasing their potential to prey on the seal pups.

Polar bears are the top predators of the sea ice ecosystem. Because they prey primarily on ice-associated seals, they are especially vulnerable to the disappearance of sea ice. The rapid rate of warming in Alaska and the rest of the Arctic in recent decades is sharply reducing the snow cover in which polar bears build dens and the sea ice they use as foraging habitat. Female polar bears build snow dens in which they hibernate for four to five months each year and in which they give birth to their cubs. Born weighing only about one pound, the tiny cubs depend on the snow den for warmth. The bear's ability to catch seals depends on the presence of sea ice. In that habitat, polar bears take advantage of the fact that seals must surface to breathe in limited opening in the ice cover. In the open ocean, bears lack a hunting platform, seals are not restricted in where they can surface, and successful hunting is very rare. On shore, polar bears feed little, if at all. Recent U.S. Geological Survey analysis suggests that two thirds of the world's polar bears will be gone by the middle of this century, and that Alaska's polar bears will be extinct within 75 years.

Continued warming will inevitably entail major changes in the sea ice ecosystem, to the point that its viability is in jeopardy. Some species will become extinct, while others may adapt to new habitats. The chances of species surviving the changes underway may depend critically on the rate of change. The current rates of change in the sea ice ecosystem are very steep relative to the life spans of animals like seals, walruses and polar bears, and as such, are a major threat to their survival[18].

Adaptation Strategies for Natural Environment and Biodiversity

Helping existing ecosystems adapt to climate change over the next few decades generally involves reducing other stresses on those systems and attempting to optimize their resilience. Beyond the next few decades, managers are likely to be faced with substantially changed conditions, requiring revised management goals and adaptation strategies. Although reducing existing stresses is a reasonable strategy for the present and other potential strategies can be identified for the future, they are largely untested and their effectiveness and costs are poorly understood. It will be critical for the institutions responsible for managing these ecosystems to collaborate on larger regional strategies than is currently the case.