4 Effects on Ecosystems

OVERVIEW

As previously stated, one of the most misunderstood aspects of climate change is not the rise in air temperature by a few degrees—it is the sheer havoc that those "few degrees" will wreak not only on human society but on the natural environment. One aspect of human nature is that if something is not directly affecting us, it probably will not make a lasting impression. For instance, consider this: Every time something upsets the balance in the Middle East and the price of gas skyrockets at the pumps as a result, people complain, drive less, maybe put their Sport Utility Vehicle's (SUV's) up for sale, seriously consider buying a hybrid, adopting a greener lifestyle, and talking about the environment and recycling. Then, right after the prices fall again at the pump, people get comfortable in their "business as usual" ways, and that is the end of it until the next panic at the pumps. What percentage of the general public do you suppose really takes it seriously and follows through for the environment?

If we had to trade places with someone or something that had to live with the permanent consequences of climate change every day, perhaps that would generate the interest and dedication necessary to make real and permanent changes. Knowledge is power, and that is what this chapter's purpose is: to give you a basic, fundamental understanding of exactly how climate change is currently affecting—and will affect—the earth's varied ecosystems.

This chapter will discuss six unique ecosystems and the effect that climate change is currently having, what will happen as temperatures continue to rise, and what the future will look like for the inhabitants of these areas. First, it will take a look at the world's forests—the temperate, boreal (northern), and tropical so that you can get an idea of the destruction affecting these areas. Next it will focus on the world's grasslands and prairies. Following that, we will focus on the earth's most fragile ecosystem—the polar areas. Most of these areas are already feeling the disastrous effects of the warming temperatures. From there, we will travel to the world's great deserts, then mountain areas, and finally to the diverse aquatic regions—lakes, oceans, and coastal areas—where many of the world's most heavily populated urban areas are located, so that you will see why the problem is much more than just a few degrees' rise in temperature.

INTRODUCTION

The earth's ecosystems are each diverse and unique. They vary, sometimes drastically, from one another, and each offers its own blend of life forms, services, and purpose to this complicated planet. They are each rich in their own resources—irreplaceable if they are lost.

Currently, one of the biggest threats to their existence is climate change, caused principally by the action of human activity: chiefly the burning of fossil fuels but also other activities such as deforestation. Changes to ecosystems are being felt worldwide as climates are beginning to shift—some more subtle than others. Documented changes include the dying off of endemic vegetation, migration of vegetation northward (in the Northern Hemisphere), migration of animal species to cooler environments (northward in latitude and higher in elevation in mountainous areas), migration of grasslands and food belts, melting of ice caps and glaciers, loss of sea ice, loss of crucial animal habitat, increased incidences of drought and desertification, increased occurrence of heat waves, an upsurge in wildfire incidences, changes in mountain regimes, an increased lack of mountain water storage, sea-level rise and flooding in coastal regions, die-off of tropical coral reefs, and saltwater contamination in fragile wetland areas. Each one of these changes to the ecosystem they affect causes a negative impact of some type on the life that lives in them. For the birds that migrate, it might mean a 2-week delay in flowering times of local plants and a subsequent lack of food supply. For a dry region suffering from the effects of drought or desertification, it may mean the lack of a food crop during a growing season desperately needed to support several villages. For the polar bear, it may mean the permanent melting of hunting and breeding grounds, restricting where they can travel, thrive—and to some it may spell death.

This chapter will illustrate the effects climate change is having, and will have, on the earth's major ecosystems, what to expect as temperatures steadily climb, and why it is so crucial that this process humans have set in motion be halted now before any more damage is done to the fragile ecosystems that will have no choices once series of events have been set in motion.

DEVELOPMENT

The Intergovernmental Panel on Climate Change (IPCC)'s Climate Change 2014 Synthesis Report: Summary for Policymakers, which is based on the reports of the three Working Groups of the IPCC, including relevant special reports, provided observed changes and their causes, supplying an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report in 2014. A summary of their findings is shown in Tables 4.1 and 4.2.

TABLE 4.1

Habitats Threatened and Endangered by Climate Change

Coral Reefs	Mountain Ecosystems
Coastal wetlands	Prairie wetlands
Mangroves	Ice edge ecosystems
Permafrost ecosystems	

Estimates by the IPCC in their Fifth Assessment Report indicate that 25 percent of the earth's mammals and 12 percent of birds are at significant *global* risk of extinction. Although there are also other stresses on animal habitats, such as exploitation, pollution, extreme climatic events, and diseases, climate change is a significant issue affecting their health and survival, and continuing climate change will increase species' vulnerabilities to rarity and extinction (high confidence level) (IPCC, 2016).

TABLE 4.2

Summary of the IPCC's Findings on Climate Change, 2014

Observed changes and their causes	Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.
Observed changes in the climate system	Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes have been unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.
Causes of climate change	Anthropogenic greenhouse gas emissions have increased since the preindustrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane, and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-twentieth century.
Impacts of climate change	In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.
Extreme events	Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels, and an increase in the number of heavy precipitation events in a number of regions.
Future climate changes, risks, and impacts	Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.
Key drivers of future climate	Cumulative emissions of CO_2 largely determine global mean surface warming by the late twenty-first century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socioeconomic development and climate policy.
Projected changes in the climate system	Surface temperature is projected to rise over the twenty-first century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The oceans will continue to warm and acidify, and global mean sea level to rise.
Future risks and impacts caused by a changing climate	Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development.
Climate change beyond 2100, irreversibility, and abrupt changes	Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases.
Future pathways for adaptation, mitigation, and sustainable development	Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emission reductions over the next few decades can reduce climate risks in the twenty-first century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development.
Foundations of decision-making about climate change	Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments, and diverse perceptions and responses to risk and uncertainty.
Climate change risks reduced by mitigation and adaptation	Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the twenty-first century will lead to high to very high risk of severe, widespread, and irreversible impacts globally (high confidence). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread, and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.

Source: (IPCC. 2014a).

In the IPCC's Fifth Assessment Report of 2014, they concluded that

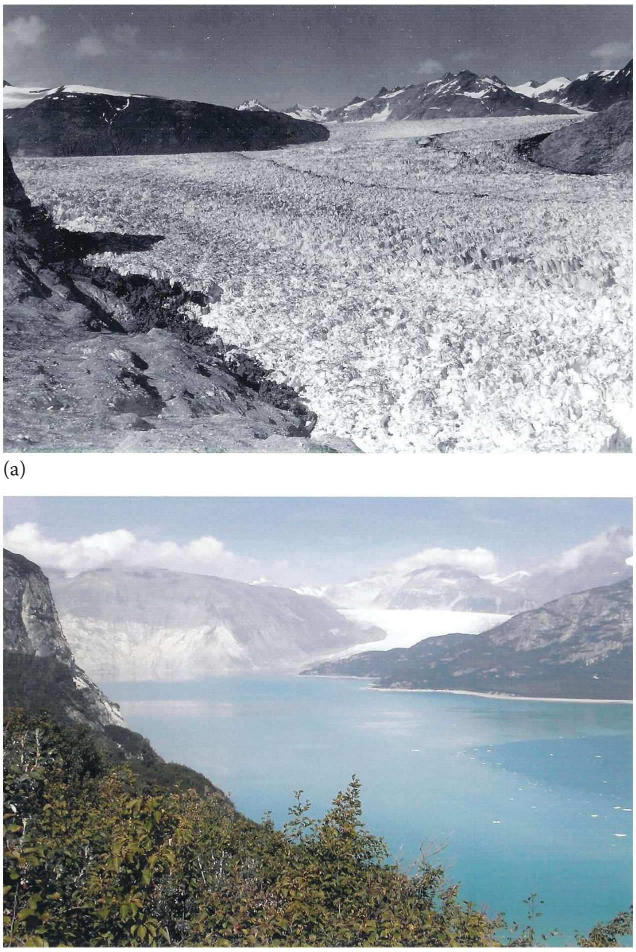
> Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. (IPCC, 2014b)

In these studies, scientists have been able to break down the natural and human-caused components in order to see how much of an effect humans have had. Human effects can include activities such as burning fossil fuels, certain agricultural practices (such as heavy use of fertilizers and other chemicals, tillage, mismanagement of livestock waste, irrigation erosion, introduction of invasive species, and soil compaction), deforestation, and local pollution from certain industrial processes (such as uncontrolled emissions, chemical use, and noncompliance of specific regulations), the introduction of invasive plant species, and various types of land-use change (such as urbanization, industrialization, and mismanaged recreational activities).

In many cases, scientists do not need to look very far to see the effects a warming world is having on the environment and the earth's ecosystems. Glaciers worldwide are melting at an accelerated rate never seen before (Figure 4.1). The cap of ice on top of Kilimanjaro is rapidly disappearing; the glaciers that have made Glacier National Park in the United States world renowned, and also extend across the border into Canada, are melting and projected to be gone within the next few decades; and the glaciers in the European Alps are experiencing a similar fate.

In the world's tropical oceans, vast expanses of beautiful, brilliantly colored coral reefs are dying off as oceans slowly become too warm. Unable to survive the higher temperatures, the corals are undergoing a process called "bleaching" and are turning white and dying off at rapid rates. In the Arctic, as temperatures climb, ice is melting at accelerated rates, leaving polar bears stranded, destroying their feeding and breeding grounds, causing them to starve and drown (Figure 4.2). Permafrost is melting at accelerated rates. As the ground thaws, it is disrupting the physical and chemical components of the ecosystem by causing the ground to shift and settle, toppling buildings and twisting roads and railroad tracks, as well as releasing methane gas into the atmosphere (another potent greenhouse gas responsible for climate change).

Weather patterns are also changing. El Niño events are triggering destructive weather in the eastern Pacific (in North and South America). Extreme weather events and droughts have become more prevalent in some geographical areas, such as parts of Asia, Africa, and the American Southwest. Animal and plant habitats have been disrupted, and as temperatures continue to climb, there have been several documented migrations of individual species moving northward (toward the poles) or to higher elevations on individual mountain ranges. Migration patterns are also being impacted, such as those already documented of beluga whales, butterflies, and polar bears. Spring, arriving earlier in some areas, is now influencing the timing of bird and fish migration, egg laying, leaf unfolding, and spring planting for agriculture. In fact, based on satellite imagery documentation of the Northern Hemisphere, growing seasons have steadily become longer since 1980.



(a)

(b)

FIGURE 4.1 The Muir Glacier located in Alaska. Photo (a) was taken in 1941, and the photo (b) was taken in 2004. The massive melting that has taken place is attributed largely to anthropogenic warming of the atmosphere. (Courtesy of National Snow and Ice Data Center, Boulder, Colorado; photo (a) by William O. Field, glaciologist for the National Park Service; photo (b) by Bruce F. Molnia, geologist for U.S. Geological Survey.)

Although species have been faced with changing environments in the past and have been able to adapt in many cases, the IPCC scientists view this current rate of change with alarm. They fully expect the magnitude of these changes to increase with the temperatures over the next century and beyond. The concern is that many species and ecosystems will not be able to adapt as rapidly as the effects of climate change cause the environment to change. In addition, there will also be other disturbances along with climate change, such as floods, insect infestations, and spread of disease, wildfire, and drought. Any of these additional challenges themselves can destroy a species or habitat. In particular, alpine (high mountain top) and polar species are especially vulnerable to the effects of climate change because as species move northward (poleward) or higher in elevation on mountains, these species' habitats will shrink, leaving them with nowhere else to go.

FIGURE 4.2 Polar bears are in a precarious situation right now. As the Arctic ice retreats, polar bears are struggling to survive. Lack of ice takes away valuable hunting and breeding grounds as well as migration corridors. (Courtesy of Publitek, Inc., Waukesha, WI.)

Climate zones could shift, completely disrupting land-use practices. For instance, the current agricultural region of the Great Plains in the United States could be shifted instead toward Canada. The southern portion of the United States could become more like Central or South America. Siberia would no longer be a frozen, desolate landscape. Parts of Africa could become dry, desolate wastelands. If this were to happen, it would severely impact the production of agriculture and the agricultural-related industries. Areas where it's currently economically feasible to farm would no longer have the climatic conditions to do so; and areas that may suddenly have a favorable climate for farming may not have fertile soils and would have no farming infrastructure to make it economical. The ripple effect of these disruptions would be felt worldwide. Millions of people would be forced to migrate from newly uninhabitable regions to new areas where they could survive. There would be enough of a disruption that ecosystems worldwide would be thrown out of balance and altered. If, however, the temperature rise falls toward the higher end of the estimate, the results on ecosystems worldwide would be disastrous. There would also be impacts of climate change on public health as a result. Rising seas would contaminate freshwater with saltwater; there would be more heat-related illnesses and deaths; and disease-carrying rodents and insects, such as mice, rats, mosquitoes, and ticks, would spread diseases such as malaria, encephalitis, Lyme disease, and dengue fever.

Scientists of the IPCC agree that one of the most serious aspects of all this drastic change is that it is happening so rapidly. These changes are happening at a faster pace than the earth has seen in the past 100 million years; although humans may be able to pick up and move to a new location, animals and their associated ecosystems cannot. Unfortunately, the choices humans make and actions they take today are determining the fate of other life and their ecosystems tomorrow.

Results of Climate Change on Ecosystems

World Wildlife Fund scientists believe that climate change could begin causing extinction of animal species in the near future because the heating caused by accelerated climate change severely impacts the earth's many delicate ecosystems—both the land and the species that live within them. Worldwide, there are several species and habitats that have now been identified as being threatened and endangered due to the effects of climate change, which are listed in Table 4.3. Because ecosystems can be altered to the point where the damage becomes irreversible and species must adapt to survive or they will die, it is critical that the issue of climate change be addressed and acted upon now before it is too late.

TABLE 4.3
Some Species Threatened and Endangered by Climate Change

Polar bear (*Ursus maritimus*)	Sea turtles Loggerhead: *Caretta caretta* Leatherback: *Dermochelys coriacea* Hawksbill: *Eretmochelys imbricata* Kemp's ridley: *Lepidochelys kempii* Olive ridley: *Lepidochelys olivacea* Flatback: *Natator depressa*
North Atlantic right whale (*Eubalaena glacialis*)	Giant panda (*Ailuropoda melanoleuca*)
Marine turtles (multiple *chelonian* species)	Pika (*Ochotona princeps*)
Multiple bird species (mountain, island, wetland, Arctic, Antarctic, seabirds, migratory birds) (*Avian*)	Wetland flora and fauna
Snowy owls (*Nyctea scandiaca*)	Salt wetland flora and fauna
Mountain gorilla (Africa) (*Gorilla beringei beringei*)	Cloud forest amphibians
Andes spectacled bear (*Tremarctos ornatus* or Andean bear)	Bengal tiger (*Panthera tigris tigris*)
Staghorn corals	Arctic fox

Source: (World Wildlife Fund, 2015).

One of the most serious constraints on animal and plant adaptation is interrupted migration. Migration for many species, such as geese, elk, salmon, leatherback turtles, wildebeest, and monarch butterflies, is a natural annual act. As climate change impacts ecosystems worldwide, many species unable to survive in the new climatic conditions of the geographic areas where they have always lived will need to migrate to areas with new climates they can survive in. There are several potential problems with this, however. Under the effects of climate change, the environment may change faster than a species can adapt. In other cases, existing land use—such as heavily urbanized areas—may negatively impact wildlife habitat. Wide-ranging wildlife species need secure core habitat where human activity is limited, ecosystem functions are still intact, and wildlife populations are able to flourish. If they do not have this, their long-term health and survival will be negatively impacted. In this situation, corridors connecting core areas are important to have established before the effects of climate change are felt. According to the U.S. Fish and Wildlife Service, it is imperative to save species. Endangered species are nature's "911" because they often serve as an early warning sign for pollution and environmental degradation that can affect human health.

Impacts to Forests

Forests are products of hundreds of millions of years of evolution. During this time, natural climate cycles have caused forests to adapt by changing the types of vegetation that live within them and by migrating to new habitats as conditions gradually change. As this has occurred in the past, it has happened at a much slower pace, allowing forests to successfully adapt. Today, changes in climate (temperature, precipitation, humidity, and air flow) are happening at a much more rapid pace, and forests have not had the luxury of time to adapt.

Forests are extremely valuable ecosystems—they help to regulate rainfall and are also key sources of food and medicine. They provide abundant wildlife habitat, carbon storage, clean air and water, and recreational opportunities. They also provide a bounty of natural resources, such as wood, plants, berries, water, wildlife, and aesthetic values. The health and diversity of forests is largely influenced by climate. Native forests adapt to the local climate features. For example, in the far-northern boreal forests, cold-tolerant species, such as white spruce, have adapted there; in drier areas, conifer and hardwood forests thrive because they need less water. Because air temperature affects the physiological processes of individual plants and productivity, the effects of climate change have a strong influence on the health of tomorrow's forests. Not all forests will have the same outcomes under the influence of climate change. Some forests will die back, whereas others may extend their ranges. Amounts of CO_2 will vary as well. Whatever the outcome of a particular forest, if the population cannot adapt or migrate with the changes, they will face extinction.

According to the IPCC, at least one-third of the world's remaining forests may be negatively impacted by climate change during this century. It may force plant and animal species to migrate or adapt faster than they physically can, disrupting entire ecosystems. The IPCC also predicts that forests will have changes in fire intensity and frequency and increased susceptibility to insect damage and diseases (IPCC, 2016).

Climate scientists are currently employing a variety of methods to predict the impacts of climate change on forests. On a global, or a large regional, scale, they are predicting shifts in ecosystems by combining biogeography models with atmospheric general circulation models (GCMs) that project changes in an environment where the CO_2 content has doubled. They also use biogeochemistry models to simulate the carbon cycle; flow of nutrients; and changes in precipitation, soil moisture, and temperature to study ecosystem productivity. They have developed global models that simulate worldwide changes in vegetation composition and distribution.

The IPCC states that climate change both directly and indirectly affects the health of forests. The direct impacts of warmer temperatures, changing rainfall patterns, and severe weather events can already be seen in certain tree and animal species (IPCC, 2016). Even small changes can affect forest growth and survival—especially the portions that lie along the outer edges of the ecosystem where the conditions are marginal. When it gets hotter, more water is lost through evapotranspiration, which causes drier conditions and decreases the vegetation's use of water. Water temperatures can also throw off the timing of flowering and fruiting for plants and adversely affect their growth rate. Forests will also be threatened when the seasonal precipitation patterns they have been used to change; water is not supplied when it is needed, causing drought conditions and stress, or supplied too much when it cannot be assimilated, causing flooding and mudslides.

Natural Resources Canada (2016) has found that the age and structure of the forest also plays an important role in determining how quickly a forest responds to changes in moisture conditions. Mature forests have well-established root systems, enabling them to tolerate drought better than younger forests or forests that have been disturbed in some other way, such as through disease infestation. Species type also plays a part—some species are more resistant than others.

Canadian researchers have identified 141 potential climate change indicators. They then selected seven of those to focus on for their value in raising awareness of ongoing changes and their ability to track and report on, and provide valuable information for dissemination. Those indicators fall within three general categories: climate, forest, and human. Although all indicators are affected in some way by other factors, they are useful for studying the effects of climate change and its mitigation in a practical way. The seven factors they are focusing on in their model are as follows, as an example of a practical approach in dealing with the real effects of climate change in a forest system:

1. The climate system
   a. *Drought*: Why is drought important, what has changed, what are adaptation tools and resources available?
   b. *Fire weather*: How has the length of the fire season increased/changed?
2. The forest system
   a. *Distribution of tree species*: Why is the distribution of tree species important with its interaction to the environment (water and nutrient cycling, competition, etc.).
   b. *Fire regime*: Wildland fire regimes influence the ecosystem and affect forest resource availability and human safety, health, and property.
   c. *Tree mortality*: It provides a measure of forest health and also affects the carbon balance.
3. The human system
   a. *Cost of fire protection*: Significant resources are invested to protect both forest and public resources.
   b. *Wildland fire evacuations*: Emergency evacuations prevent injury and death when wildfires threaten communities.

In the short term (50–100 years), changes due to climate change will be focused on ecosystem function. In the long term, shift of forest types will be more significant. Boreal forests will be impacted the most severely, as their ecosystem will be greatly reduced because significant warming is expected in the polar regions. According to Dmitry Schepaschenko of Austria's Institute for Applied Systems Analysis, "The changes could be very dramatic and very fast." In a study focused on climate change effects on boreal forests, he has discovered that climate change is forcing the boreal forests that cover the majority of Northern Canada to the tipping point. The study was done in conjunction with three authors, including Dmitry Schepaschenko of Austria's Institute for Applied Systems Analysis; another scientist from Natural Resources Canada who was unable to speak on record due to federal restrictions; and a third scientist who remained unidentified. They report that, although the region remains largely intact, it faces the most severe expected temperature increases anywhere on the earth. They predict that parts of Siberia will likely become 11°C warmer. The expected results include greater precipitation, but not enough to remediate the dryness caused by the hotter weather. This means that a drier boreal forest will suffer from new diseases, insect infestations, and uncontrollable wildfires (Weber, 2015).

Some of the most vulnerable temperate forests will be the "island" or isolated forest communities, such as the fragmented forests encroached upon by urban and agricultural areas. They will also be at risk because there will be no migration options. Forests located in the high elevations on mountain systems face a similar threat—as they migrate upward, eventually there will be nowhere left to migrate. Individual species that are indigenous to small geographic areas or have limited seed dispersal will also be threatened and endangered. Under climate change conditions, surviving forests of the future are expected to look very different from those of today. Although changes will vary in degree from area to area, all forests will be affected in some manner. Impacts of climate change are already manifesting, such as forests in the United States and Canada. Over the past century, a 1°C–2°C increase in air temperature and changes in precipitation have already been documented. Experts believe that higher levels of CO_2 have already caused forest dieback of forested areas along the Pacific and Atlantic coasts (Weber, 2015).

It is expected that temperate forests in the United States will migrate northward from 100 to 530 kilometers over the course of the next century. If the air temperature warms 2°C over the same time period, models have predicted that tree species will have to migrate from 1.6 to 4.8 kilometers per year, which is too fast for most temperate species, except for those whose seeds are carried by birds over greater distances. As a result, it is expected that grasslands will dominate many of these areas.

The effects of climate change are felt most at the poles, where the predicted rise in temperature could climb 5°C–10°C or higher over the next century. It is estimated that warming will negatively affect the species that live in the ecosystems and that approximately 24–40 percent of the species living in the boreal forests right now will be lost. Species that live in the north will be crowded out by species from the temperate regions that will be migrating northward in search of cooler climates. The species that will invade the present boreal forests will be today's temperate forest species and grasslands. As the boreal forest vegetation is forced out, it will migrate poleward 300–500 kilometers during the next century. Proof of this can already be seen in Western Canada, as their plant zones have already begun shifting poleward (IPCC, 2014b). Migrating vegetation will encounter severe challenges, however. For example, the soils in the tundra region are not fertile and conducive to high-density vegetation or tree growth. They lack the biota necessary for colonization. Specific seed dispersal rate and migration tolerance range are also the important factors that could play a role in keeping trees from being able to survive the poleward migration rate dictated by climate change.

There are other factors that will hurt species migration as well, such as habitat fragmentation (small isolated population clusters rather than one large cohesive unit) and competition from more hardy species. As temperatures change, it may also affect the timing and rate of seed production, which will affect the growth and strength of the trees. Trees that have limited seed dispersal mechanisms will also suffer. For instance, trees whose seeds are carried long distances by the wind will have a better chance of survival than those whose seeds fall closer to the tree.

The ability to adjust to a larger temperature range will also play an important role. Vegetation with narrow temperature tolerances will be vulnerable to extinction. The IPCC (2014b) has stated that a drastic change in species composition and loss of habitat with even a 2°C warming near the poles will damage the ability of an ecosystem to function as species richness begins to be killed off.

In a study conducted by Natural Resources Canada, an average rise in temperature of 1°C over Canada in the last century has had a negative impact on vegetation. At mid to high latitudes (45°N–70°N), plant growth and the length of the growing season have increased. In portions of Western Canada, there has been a decrease in rainfall as temperatures have risen and this has hurt the growth of some tree species, such as aspen poplar. In Alberta, aspen are now blooming 26 days earlier than they were a hundred years ago (Kerr, 2009).

Another major concern for boreal forests in a warmer climate is insect infestations. Insects commonly found in temperate forests, such as mountain pine beetle, will migrate north along with the forests and continue to infest and infect as they move northward, devastating industries such as logging and tourism.

As temperatures climb, drought-like conditions may develop. If this happens, there will also be greater incidences of wildfire. In the past 40 years, the trend has already been established that as climate warms, wildfires have become more frequent and are burning larger areas. This overall trend has been seen in places such as southern California, and also in boreal locations in Canada and Russia. As climate change continues, longer fire seasons, drier conditions, and more frequent severe electrical storms are projected to increase, causing the fire season to become more problematic and devastating as the climate continues to change.

Although it is true that some forest species' seeds are actually dispersed by fire, which will aid their migration, and burnt litter will add nutrients to the soil, over time reoccurrences of wildfire will fragment established vegetation colonies and make it more difficult for them to migrate. In addition, as older trees burn, they will add carbon to the atmosphere, and as younger trees replace these burnt areas, there will be less initial carbon storage capability.

The world's tropical forest ecosystems are very sensitive to disturbances such as overgrazing, logging, plowing, and burning. Converting natural ecosystems to agricultural and logging uses combined with climate change is the largest threat to the rain forests today. According to the Food and Agriculture Organization (FAO) of the United Nations, a land area the size of Ireland or South Carolina (13 million hectares) is lost to these uses every few years in the rain forests. From the mid-1990s to the present, more than 100 million hectares of tropical rainforest has been deforested (FAO, 2010). Developing countries are hit harder than developed countries. Unfortunately, it is often seen as necessary to farm the land in pursuit of food or sell the land to logging companies in exchange for needed income.

According to Jose Antonio Marengo of Brazil's National Space Research Institute, if the issue of climate change is not addressed today, the rain forests will be negatively impacted. They will receive less rainfall in addition to experience higher temperatures, enough so that it could transform the Amazon—the world's largest remaining tropical rain forest—into a savanna (grassland) by the end of the century. The Amazon covers almost 60 percent of Brazil and hosts one-fifth of the world's freshwater and nearly 30 percent of the world's plant and animal species. Marengo is involved in research focused on the following two different scenarios:

1. If no action is taken to slow or halt climate change or deforestation, temperatures will rise 5°C–8°C by 2100, and rainfall will decrease by 15–20 percent. This is the scenario that would transform the Amazon into a savanna.
2. If action is taken now to slow climate change, temperatures would most likely rise 3°C–5°C by 2100, and rainfall will decrease by 5–15 percent.

Marengo stresses that "if pollution is controlled and deforestation reduced, the temperature would rise by about 5°C by 2100. Within this scenario, the rain forest will not come to the point of total collapse." He also stated that he was optimistic that the worst-case scenario could be averted, but that it would require a major effort by industrialized nations to reduce emissions of greenhouse gases, such as carbon dioxide (Environmental and Energy Study Institute, 2007).

Unfortunately, many of the world's rain forests are being cut down at an accelerated rate for agriculture, pasture, mining, and logging. When these forests are cut down or burned, huge amounts of carbon are reintroduced back into the atmosphere. Tropical deforestation accounts for about 20 percent of the human-caused carbon dioxide emissions each year to the earth's atmosphere. This makes deforestation of the rain forests an important issue when dealing with the challenges of climate change.

THE FACTS OF DEFORESTATION

- Forests cover 30 percent of the earth's land.
- It is estimated that within 100 years, there will be no rainforests.
- Agriculture is the leading cause of deforestation.
- One and a half acres of forest is cut down every second.
- Loss of forests contributes 12–17 percent of annual greenhouse gas emissions.
- The rate of deforestation is equivalent to losing 20 football fields every minute.
- There are more than 121 natural remedies that we currently know of from the rainforest which can be used as medicines.

- The United States has less than 5 percent of the world's population, yet consumes nearly one-third of the world's paper.
- The Amazon rainforest produces 20 percent of the world's oxygen.
- Up to 28,000 species are expected to become extinct by the next quarter of the century because of deforestation.
- Half of the world's tropical forests have already been cleared.
- Approximately 4500 acres of forests are cleared every hour by forest fires, bull dozers, and machetes.
- Poverty, overpopulation, and unequal land access are the main causes of man-made deforestation.
- Industrialized countries consume 12 times more wood and its products per person than nonindustrialized countries.
- Soil erosion, floods, wildlife extinction, increase in climate change effects, and climate imbalance are some of the effects of deforestation.
- Worldwide, more than 1.6 billion people rely on forest products for all or part of their livelihoods.
- Tropical forests, where deforestation is most prevalent, hold more than 210 gigatons of carbon.
- Tropical rainforests contain over half of all the plant and animal species in the world.
- Deforestation affects the water cycle. Trees absorb groundwater and release the same into the atmosphere during transpiration. When deforestation occurs, the climate automatically changes to a drier one and also affects the water table.
- The world's forests store 283 billion tons of carbon present in the biomass.
- Forty-four percent of junk mail goes unopened.
- On average, each person in the United States uses more than 700 pounds of paper every year.

(*Source*: Conserve Energy Future, Deforestation facts, http://www.conserve-energy-future.com/various-deforestation-facts.php [accessed August 20, 2016], 2016.)

In view of the impacts that may be felt by the world's forests—temperate, boreal, and rain forest—it is important to begin looking at adaptation strategies today. The World Wildlife Fund has suggested the following as viable adaptation options in order to reduce the threat on forest ecosystems from climate change:

- Reduce present threats that could harm the ecosystem, such as prevent degradation and the introduction of invasive species.
- Manage large areas of land in a comprehensive way tied to the landscape. Focus on all the components that compose a large-scale area and plan for the adaptation migration of different species.
- Provide buffer zones and flexibility of land uses. The land must be managed to accommodate the movements of species migration.
- Protect mature forest stands. Mature trees are better able to withstand large-scale environmental changes and also provide a safe habitat for other species to adapt within.
- Maintain the natural fire regime. Different ecosystems have different fire ecologies, necessitating the development of fire management plans.
- Pests must be actively managed. Because climate change is associated with invasions of insects, disease, and exotic species, healthy management practices must be set in place to protect the forests. This could include measures such as prescribed burning and nonchemical pesticides.

Different forested areas will require different monitoring, planning, and protection strategies; it is imperative that humans understand the unique forest ecosystems and their value (World Wildlife Fund, 2003).

Impacts to Rangelands, Grasslands, and Prairies

Native grasslands cover about one-quarter of the world's land surface, making them a significant component of the world's vegetation. Therefore, any impact on them could seriously impact a major global ecosystem. The extent and health of natural grasslands are typically controlled by rainfall and fire. These two factors limit the extent of their range; with an increase in climate change, it is already known that there will be a decrease in rainfall in some areas and an increase in wildfire.

The world's grasslands stand to face serious consequences if climate change continues. These regions of the world provide grains and crops for the world's population, rangeland for cattle and sheep, and habitat for wildlife, and play a role in carbon sequestration and maintaining an overall healthy ecological balance in nature. Grasslands are also important for carbon storage. Whereas carbon is stored in trees, plants, and organic matter on the surface of the soil in forests, in grasslands it is stored in the soil. Because of human development, most of the earth's grasslands suitable for agriculture have already been developed. According to the FAO, as much as 70 percent of the earth's 1.3 billion hectares of grasslands have become degraded, mostly due to overgrazing (Conant, 2010).

Temperate grasslands are located north of the Tropic of Cancer (23.5°N latitude) and south of the Tropic of Capricorn (23.5°S latitude). The four major temperate grasslands of the world are the plains of North America, the veldts of Africa, the steppes of Eurasia, and the pampas of South America. Dominant vegetation types in these areas are grasses. The principal places that trees, such as cottonwood, oak, and willow, are found are along river valleys, growing in areas near a reliable water source. The soil in temperate grasslands is nutrient rich due to the growth and decay of deep, dense grass roots. The roots serve to hold the soil together as a cohesive unit. In fact, some of the world's most fertile soils are found in the grasslands of the eastern prairies in the United States, the steppes of Russia and Ukraine, and the pampas of South America.

Tropical grasslands are located near the equator, between the Tropic of Cancer and the Tropic of Capricorn. These are the grasslands that occupy Africa, Australia, India, and South America. Tall grasses dominate these landscapes—and they are found in tropical wet and dry climates, where temperatures never fall below 18°C. Usually dry, there is a season of heavy rain, bringing an annual rainfall of 51–127 centimeters per year. One of the biggest threats to the tropical grasslands with increased climate change is desertification.

In the IPCC's Fourth Assessment Report, they state that the structure and function of the world's grasslands makes them one of the most vulnerable to global climate change of any of the terrestrial ecosystems. Grasslands are vulnerable to vegetation change caused by changing temperatures and precipitation due to climate change (IPCC, 2007b).

GCMs referenced by the IPCC predict grassland ecosystems will experience climatic changes such as higher maximum (daytime) and minimum (nighttime) temperatures, and more intensive precipitation events. Recent studies of climate change processes reveal a surprising situation—daytime high temperatures are not causing problems, whereas nighttime high temperatures are causing problems. The situation is most pronounced during late winter and early spring. Nighttime high temperatures have risen, changing the temperature regime enough that the last frost date occurs on average two weeks earlier now than it did 20 years ago. In addition, native grasses are now germinating later. Invasive and noxious plants that have invaded grasslands over the years are germinating early, taking the moisture out of the soil and using the nutrients that would have been available for the grasses. In addition, cattle grazing occurs on much of the grassland areas, and the animals do not ingest the weeds, which further promotes their invasion.

Based on the results of the IPCC studies, in the world's grasslands that are expected to receive an increase in precipitation, such as the western United States, these areas may not be faced with the drying out resulting from lack of water and rising temperatures, but these areas may suffer from accelerated nutrient cycling, which in turn could encourage the spread of more invasive species. In the hot desert grasslands (such as Australia, the Sonoran and Chihuahua deserts of Mexico, and the United States), GCMs predict an increase in the frequency of intense rainfall and flash floods. These areas are expected to have increased erosion and nutrient loss. In ecosystems that have already been disturbed in other ways, such as by wildfire or with desertification, they will be impacted even more and have a more difficult time surviving under climate change conditions (IPCC, 2007b).

There are several threats to grasslands in the face of climate change. Marginal grasslands could be converted into deserts as rainfall decreases. The threat of desertification is all too real in many parts of the world. As areas struggle to find water to support populations, cultivate crops, and support livestock, grassland ecosystems stand to face further degradation as temperatures rise during climate change. Therefore, as climate changes, it is important for land managers to adapt to the changes as they happen and manage the land in a responsible way. One of the biggest obstacles they face with climate change is the threat of invasive species encroaching on native grassland species. Invasion of species can happen via seed deliverance by livestock, off-road vehicles, road maintenance crews, and outdoor recreationalists. Invasive species need to be dealt with immediately before they become established. Land managers will also have to put management plans in place in order to be prepared for the changes that climate change will bring.

Impacts on Polar Ecosystems

The effects of climate change will be felt the strongest in the earth's polar regions. Already temperatures have climbed by 2.4°C in some areas in polar regions, whereas the global average is 0.6°C over the past century. Weather conditions are so harsh that polar ecosystems must maintain a delicate balance to survive. In addition, because of their sensitive nature, the polar regions are sometimes the first ecosystems to show warning signs of climate change, such as acceleration in the melting of glaciers. In the Arctic, climate change is expected to be rapid and extensive. As temperatures warm up and ice melts, Arctic ecosystems will be impacted heavily over the next century. There is extensive sea ice at the periphery of the Arctic Ocean that forms and melts each year. These waters are important to the fishing industry, accounting for almost half of the total global production. Glacial decline, melting sea ice, rising sea levels, impacts on wildlife habitat, melting permafrost, impacts on native tribal inhabitants, and changes to plant life are all being affected in the Arctic today because of climate change.

Arctic ice is getting thinner and more prone to breaking. The Ward Hunt Ice Shelf, located on the north coast of Ellesmere Island, Nunavut, Canada, is one example—it was the largest single block of ice in the Arctic. About 3000 years old, it began cracking in the year 2000. By 2002, it had broken all the way through. Today it is breaking into pieces. The breakup of the Ward Hunt Ice Shelf has already caused several impacts: polar bears, whales, and walrus have changed their migration and feeding patterns; native people are having to change their hunting territories; and coastal villages are being flooded (Figure 4.3).

The Northwest Passage is another example of the extreme effects of climate change and the results of warming in the fragile polar environment. There was a time when the Northwest Passage was considered impassable. It was a highly desired route sought after by maritime merchants, a route that would save time and mileage if passable, but elusive. For most

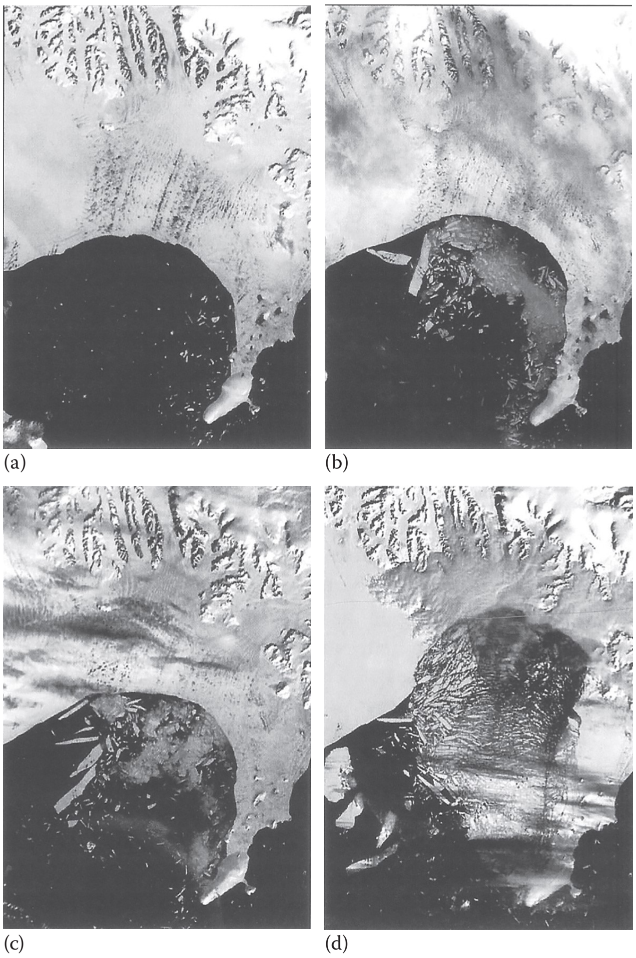


FIGURE 4.3 Large portion of the Larsen B Ice Shelf disintegrated in 2002, as evidenced in these MODIS satellite images from January 31, 2002 (a), February 17, 2002 (b), February 23, 2002 (c), and March 5, 2002 (d). Earth scientists predict that if global warming continues, incidences like this will become more common. (Courtesy of National Snow and Ice Data Center [NSIDC], Boulder, Colorado.)

of recorded history in North America, the Passage has been nearly impassable and deadly for those who have attempted its navigation. With the modernization of ships and warming of the earth with climate change, however, navigation through the Canadian Archipelago from Baffin Bay to the Beaufort Sea has become more common, although still a considerable challenge. Figures 4.4 through 4.7 illustrate the transition over time of the area in a warming environment.

Scientists for the United States Geological Survey (USGS) estimate that Alaska contains more than 100,000 glaciers (including about 60 active and former tidewater glaciers), which cover roughly 75,000 square kilometers, or about 5 percent of Alaska. The USGS has determined that most glaciers in every mountain range and island group in the state are currently undergoing significant retreat, thinning, or stagnation—most notable the glaciers at lower elevations. Some of these glaciers began this process as early as the mid-1700s. Although a few are currently advancing, more than 99 percent of them are retreating. In fact, during the past decade, Alaska's coastal glaciers have

FIGURE 4.4 Map of the Northwest Passage. (Courtesy of NASA, Washington, DC.)

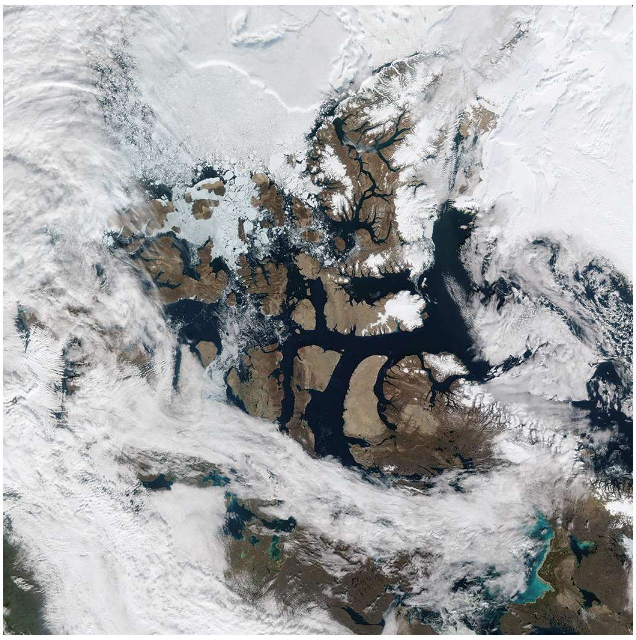


FIGURE 4.5 The Northwest Passage, Arctic partially open: The Northwest Passage as it appeared on August 31, 2015, to the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-NPP satellite. Note that much of the white covering the Northwest Passage in the VIIRS image is cloud cover, not sea ice. The Northwest Passage is a complex, winding maze of sounds, channels, bays, and straits that pass through often ice-choked Arctic waters. Mariners refer to two main routes: a southern passage and a northern passage. (Courtesy of NASA, http://earthobservatory.nasa.gov/IOTD/view.php?id=86589.)

FIGURE 4.6 Northwest Passage Open: On September 15, 2007, the MODIS on NASA's Terra satellite captured a largely cloud-free image of the Northwest Passage. Although the sea route had been characterized as nearly open weeks earlier, persistent cloud cover prevented a MODIS true-color image of the open route. Clouds do obscure parts of this image, but they remain confined to areas north and south of McClure Strait. As white as the clouds is the snow cover on some of the islands, especially around Parry Channel. Clear ocean water appears dark, but some sea ice still appears. In the east, along Ellesmere Island, faint white swirls indicate new sea ice forming at the end of summer melt season. McClure Strait also sports sea ice, and those blocky, broken up shapes suggest old sea ice undergoing melt. The generally dark color of McClure Strait could be concealing a thin layer of sea ice throughout the strait, possibly centimeters thick. (Courtesy of NASA, http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=18964.)

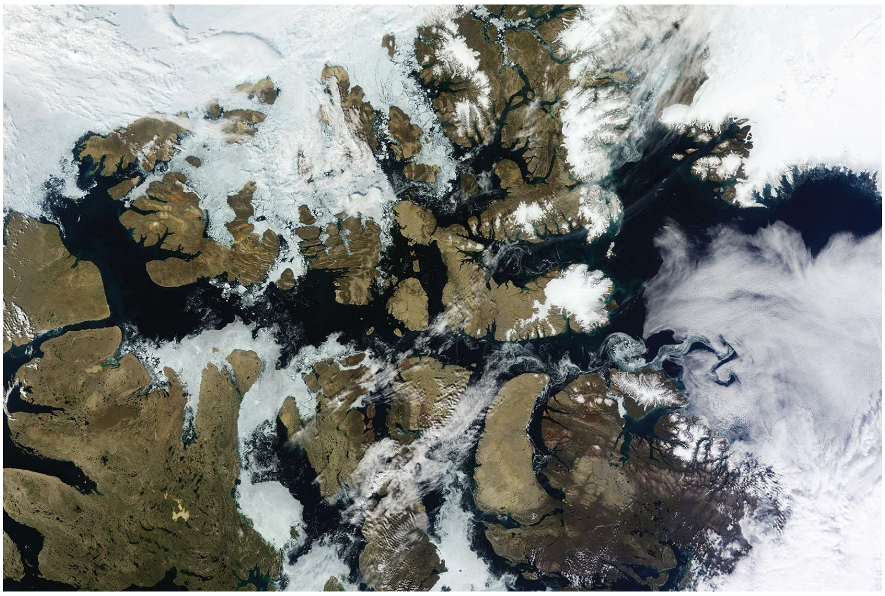


FIGURE 4.7 In late July 2012, sea ice retreated from Parry Channel in the Northwest Passage. The Canadian Ice Service reported that ice cover in the channel began to fall below the 1981–2010 median after July 16, and the ice loss accelerated over the following two weeks. The MODIS on NASA's Terra satellite captured this natural-color image of Parry Channel and McClure Strait (also known as M'Clure Strait) on August 2, 2012. Although Parry Channel was almost entirely ice free, some ice lingered between Melville and Victoria islands. In this image, that ice varies in color from nearly white to dark gray. For centuries, explorers and traders have sought an Arctic shipping shortcut between Europe and Asia. In the early twentieth century, Norwegian explorer Roald Amundsen managed to navigate the southern route of the Northwest Passage, although the journey took him nearly three years. Parry Channel occupies the northern or "preferred" route, which also opened in 2007. The southern route through the Northwest Passage opened in 2008. (Courtesy of NASA, Washington, DC.)

added as much (or more) meltwater to the global ocean as the ice sheets of Greenland or Antarctica, making these glaciers a significant factor in global sea-level rise (Puckett and Molina, 2008). The photo sequence in Figures 4.8 through 4.10 illustrates tidewater glacial calving.

In a report in the *Washington Post*, scientists at the National Oceanic and Atmospheric Administration (NOAA) say that the Arctic ice cap is melting faster than that scientists had originally expected and will most likely shrink 40 percent by 2050 in most regions, which will devastate wildlife populations, such as polar bear, walruses, and other marine animals. They also predict that Arctic sea ice will retreat hundreds of kilometers farther from the coast of Alaska in the summer. Although this could be good news for fisherman and open shipping routes and new areas for oil and gas exploration, it will spell disaster for the wildlife species that inhabit the region. In 2001, the IPCC predicted that there will be "major ice loss by 2100." Then, in 2007, when they issued their next report, they remarked that "without drastic changes in greenhouse emissions, Arctic sea ice will 'almost entirely' disappear by the end of the century." In 2014, they added that the Arctic has warmed at about twice the global rate in the past three decades. For this reason, the loss of Arctic sea ice over the past three decades—a rate of about 3.5–4.1 percent—is unprecedented. It is expected that the Northern Sea Route may have up to 125 days per year that are suitable for navigation by 2050 (CarbonBrief, 2014).

FIGURE 4.8 The Aialik Glacier, located in Kenai Fjords National Park, part of the network of tidewater glaciers at Resurrection Bay, is about 24 km (15 miles) from Seward, Alaska, a major fishing port. The massive wall of ice is constantly groaning and shifting. Pieces calve off the glacier, some quite spectacular, as can be seen in this sequence of three photos. This shows a large chunk of ice break free. (Courtesy of Kerr.)

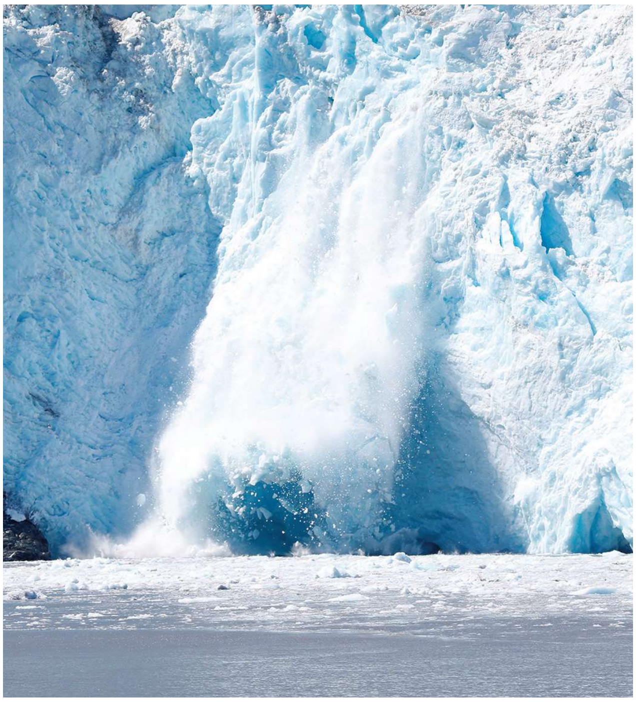


FIGURE 4.9 The mass of ice cascades to the bay below, more than 30 meters (100 feet). (Courtesy of Kerr.)

FIGURE 4.10 When the ice hits the water, the sound of the impact carries across the bay and the ice breaks apart into smaller chunks. Pieces calve off the glacier every few minutes, marking this as a glacier in retreat. (Courtesy of Kerr.)

The New York Times published a report on May 1, 2007, showing that climate scientists may have significantly underestimated the power of climate change from human-generated heat-trapping gases to shrink the sea ice in the Arctic Ocean. Dr. Julienne Stroeve, a researcher at the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado, discovered that since 1953, the area of sea ice in September has declined at an average rate of 7.8 percent per decade.

"There are huge changes going on," Dr. Stroeve says. "Just with warm waters entering the Arctic, combined with warming air temperatures, this is wreaking havoc on the sea ice." (Revkin, 2007). Since that time, the NSIDC has continued to monitor Arctic sea ice, along with scientists from NASA, recording its decline. In March, 2016, they confirmed it was at a record low maximum extent for the second straight year.

"I've never seen such a warm, crazy winter in the Arctic," said NSIDC director Mark Serreze. "The heat was relentless." Air temperatures over the Arctic Ocean for the months of December, January, and February were 2°C–6°C above average in nearly every region. Sea ice extent over the Arctic Ocean in 2016 averaged 14.52 million square kilometers on March 24, beating last year's record low of 14.54 million square kilometers on February 25. Unlike 2015, the peak in 2016 was later than average in the 37-year satellite record, setting up a shorter than average ice melt season for the coming spring and summer.

The September Arctic minimum began drawing attention in 2005 when it first shrank to a record low extent over the period of satellite observations. It broke the record again in 2007, and then again in 2012. The March Arctic maximum has typically received less attention. This changed in 2015 when the maximum extent was the lowest in the satellite record.

"The Arctic is in crisis. Year by year, it's slipping into a new state, and it's hard to see how that won't have an effect on weather throughout the Northern Hemisphere," said Ted Scambos, NSIDC lead scientist (NSIDC, 2016).

The warmer it gets, the more the glaciers melt, which adds freshwater to the ocean and upsets the earth's energy balance, ocean circulation patterns, and ecosystems. Some estimates of global sea-level rise from the Arctic melt have been placed at 1 meter by 2100. According to the U.S. Environmental Protection Agency, this increase would drown roughly 58,016 square kilometers of land along the Atlantic and Gulf coasts of the United States—specifically Texas, Florida, North Carolina, and Louisiana (Figure 4.11).

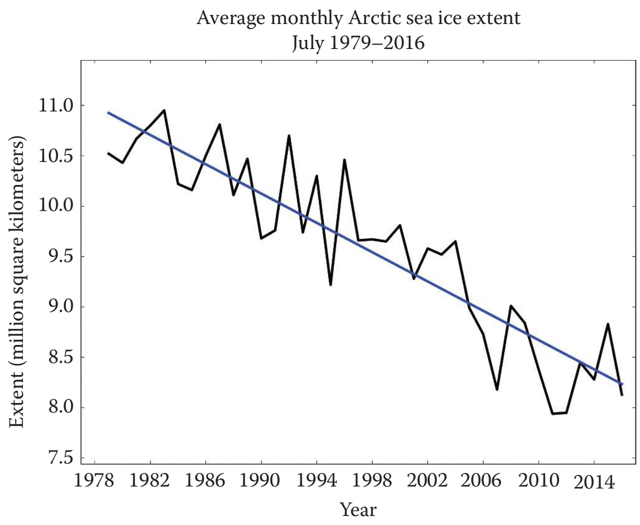
Warming in the Arctic will also affect weather patterns and food production worldwide. An example of this is given by NASA: in one of their computer models, they calculated that Kansas would be 2.4°C warmer in the winter without Arctic ice, which usually sends cold air masses into the United States. Without these Arctic-induced cold air masses, winter wheat cannot be grown and soil would be 10 percent drier in the summer, wreaking havoc on summer wheat crops (AMEG, 2016).

Since its record low in 2005, when the ice cap covering the Arctic Ocean melted to a size smaller than it had been since records began to be kept a century ago, the situation has become chaotic. In Greenland, glaciers are melting and traveling now faster to the ocean, adding freshwater. These changes in the Arctic have the potential to impact the entire earth. One of the most serious consequences could be the disruption of the thermohaline circulation, with the ramifications discussed in Chapter 2.

FIGURE 4.11 This photo, taken in Denali National Park on July 21, 2016, shows the extreme glacial melting that has taken place in the Arctic environment. Visible are the remnant cirques, prominent lateral moraines, diminished central glacier at the bottom, remaining kettle lakes, and other features signaling the rapid melting of the glaciers in the area.

The Arctic Council, an intergovernmental forum composed of eight Arctic nations (Canada, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, and the United States) and six Indigenous People's organizations, had an assessment prepared by the Arctic Monitoring and Assessment Programme, the Conservation of Arctic Flora and Fauna, and the International Arctic Science Committee of impacts on the Arctic as a result of climate change. They support the notion that the Arctic is extremely vulnerable to observed and projected climate impact, and that it is currently facing some of the most rapid and severe climate change on earth. Over the next 100 years, they report that climate is expected to change and these changes in the Arctic will be felt worldwide. Although some of these changes are those caused by nature, the overwhelming trends and patterns are a result of human influence, resulting from the emission of greenhouse gases.

One of the biggest key climate change indicators in the Arctic is the declining sea ice. Researchers actually use the quantitative amounts of Arctic sea ice as an early warning system of climate change. According to the Arctic Research Center, over the past 30 years, the average sea ice extent has decreased by 80 percent, which is the equivalent area of roughly one million square kilometers. By comparison, this represents an area roughly the size of Egypt. Of even more concern, the melting rate is accelerating. The most pronounced season of melting is in the late summer. It is projected that by 2100, late-summer sea ice will have decreased in a range somewhere from 50 percent to complete disappearance (Graph 4.1) (NSIDC, 2016).



GRAPH 4.1 Monthly July ice extent for 1979–2016 shows a decline of 7.3 percent per decade. (Courtesy of National Snow and Ice Data Center [NSIDC], Boulder, Colorado.)

Another major global impact that will occur as a result of ice sheet melting in the Arctic is sea-level rise. The Greenland ice sheet is the largest ice sheet in the Arctic. In April 2016, polar researchers were stunned when nearly 12 percent of Greenland's ice sheet began melting, as observed by scientists at the Danish Meteorological Institute, beating the previous record set in May 2010 for 10 percent melt. Temperatures on the ice were in excess of 10°C in some locations. Even a weather station located at 1840 meters above sea level recorded a maximum of 3.1°C, which data analysts said would be warm for July, let alone April (The Guardian, 2016).

Sea-level rose roughly 8 centimeters over the past 20 years, and as temperatures rise, the rate is increasing. This is due to two factors: melting ice and thermal expansion of seawater. The global average sea level is projected to rise anywhere from 10 to 90 centimeters by 2100. Some climate models have predicted that the Greenland ice sheet will completely melt, causing sea levels to rise 7 meters. By comparison, a 50 centimeters rise in sea level will typically cause a shoreward retreat of coastline of 50 meters if the land is relatively flat. This would flood areas, causing significant environmental and economic impacts (Ritter and Hanley, 2011).

Impacts of Climate Change on Desert Ecosystems

The world's principal deserts are found in two major zones: at 25°–35° latitude north and south of the equator. Desert ecosystems are defined as regions that are very arid and dry—receiving less than 25 centimeters of rain a year. By definition, deserts are not confined to just hot, dry areas—they can also exist in the cold, dry areas within polar regions. Because these regions are so physically harsh, the plants and animals that live within them have learned to adapt and survive in an extremely hostile environment. Covering about one-fourth of the earth's land surface (54 million square kilometers), they are dominated by bare soil and scarce vegetative cover.

As climate change continues, current deserts will be impacted as temperatures rise, water becomes scarcer, and food sources become problematic. As desertification spreads due to climate change, ecosystems worldwide will be impacted in some way. Understanding the fragile balances in desert ecosystems and how climate change will relate to them is important as land managers look at future management options.

Climate change is expected to cause intensification in the hydrologic cycle, with a marked increase in evaporation over land and water. The higher the evaporation rate, the greater the drying will be of soils and vegetation. In areas where there is a decrease in rainfall and an increase in evaporation, droughts will occur, be more severe, and last longer.

Drought already threatens the lives of millions of people on earth. As the atmosphere continues to warm under the effects of climate change, the negative effects and hardships brought on by drought will spread across the globe as areas heat up and dry out. Regions that are already dry are expected to become drier as climate change affects the process of evapotranspiration. This will lead to increased drought in dry areas where rivers, lakes, and groundwater levels are lower than normal, and soils in agricultural areas lack sufficient moisture, negatively impacting food production. Precipitation amounts have steadily declined in the tropical and subtropical regions since the 1970s. Areas becoming continually drier include southern Africa, the Sahel region of Africa, southern Asia, the Mediterranean, and the Southwestern United States.

With this continuing trend, scientists expect that the amount of land affected by drought to increase by mid-century, as well as water resources to decline up to 30 percent. The reason for this is due to the shifting of the Hadley Cell circulation pattern. What they foresee happening is that warm air normally rises at the tropics, loses its moisture to tropical thunderstorms, and descends in the subtropics as dry air (the Hadley Cell); as the climate warms, the atmospheric circulation will shift the circulation poleward toward higher latitudes, causing storm patterns to shift with them and expanding the region that the descending drier air will affect. Because it is a larger region, more areas will be susceptible to drought (UCS, 2011).

A NOAA measure of drought from a climate model, called the Palmer Drought Severity Index (PDSI), developed in the 1960s by Wayne Palmer, predicts there will be a notable increase during this century with predicted changes in rainfall and heat around the world because of climate change. The PDSI figure for "moderate drought" is currently at 25 percent of the earth's surface. By the year 2100, it predicts it will rise to 50 percent. The figure for "severe drought" is currently at 8 percent; by 2100, it is predicted to rise to 40 percent. The figure for "extreme drought" is currently at 3 percent; by 2100, it is predicted to rise to 30 percent, based on the study conducted by the Hadley Centre (Worldwatch Institute, 2013). What this means is that one-third of the earth's land surface will no longer be able to produce food in just a matter of a few decades. To complicate matters, the areas most prone to drought are those that are currently most densely inhabited, which means that hundreds of millions of people will no longer be able to feed themselves.

For a realistic glimpse into the future, picture this: predictions are that valleys once fertile will turn dry and brown. For inhabitants of desert valleys that rely on a short rainy season each year in order to be able to grow crops and graze their animals, they will wait in anticipation for rains that will never come. Year after year, the situation will repeat itself as millions of people near starvation. Nomadic herders' animals will die; their cattle are emaciated to skin and bones now. Bleached skeletons of cows, goats, and sheep will litter the barren, dusty landscape. Nomadic herders will set out and walk for weeks without finding a watering hole or a riverbed. As people begin dying of starvation, inhabitants of different geographic areas will start fighting each other for what slim, meager resources are still in existence.

As brutal as this may sound, if climate change continues, this scenario will become commonplace. The number of food emergencies in Africa each year has almost tripled since the 1980s. Across sub-Saharan Africa, one in three people today is undernourished (Borgen Project, 2014).

In early 2007, the world witnessed public riots and protests due to food security issues. In sub-Saharan Africa, for example, chronic food security issues hit the undernourished hard, which had harsh effects on world peace and security. A year later, this was followed by rising commodity prices. It is expected that problems will continue to escalate as climate change continues and food insecurity issues increase. Governments there have not prioritized food security as a critical issue; there are low agricultural budgets, weak institutional capacity, difficulty in coordination, and declining donations, which exacerbate the problem. In 2008, the United Nations Development Program (UNDP) warned that any positive socioeconomic developments that had been achieved during the decade with the implementation of the Millennium Development Goals program (a United Nations project designed to address extreme poverty) may be seriously impacted or reversed by climate change due to new threats to water and food security, agriculture production and access, and nutrition and public health concerns. They also warned that the impacts of climate change, such as rising sea levels, droughts, heat waves, floods, and unpredictable rainfall, could cause another 600 million people to become malnourished and increase the number of people facing water scarcity to 1.8 billion by 2080 (Mburia, 2011).

Desertification

One of the impacts that climate change may have on the surface of the Earth is to exacerbate the worldwide progression of desertification. If there is a significant decrease in the amount of rainfall reaching an arid or semiarid area, it could increase the extent of the dryland areas globally, destroying both vegetation and soils. Desertification is a degradation process inflicted on arid and semiarid landscapes due to human activities, climate change, or a combination of both. Although desertification has always existed, it has become more prominent and a much bigger concern in recent years as populations have rapidly expanded across previously untouched landscapes and arable land has been cultivated and grazed.

The first most well-known incidence of desertification in the United States was the Dust Bowl era of the 1930s, caused by a combination of drought and improper farming and land management practices. During this period of time, millions of people were forced from their homes in the biggest migration in U.S. history and forced to abandon their farms, The Great Plains were eventually restored over time through the practice of good land management plans, improved agricultural methods, and responsible conservation efforts, initiating the birth of the Soil Conservation Service. In other areas of the world, however, population explosion and increasing livestock pressure on marginally healthy land have worsened the problem of desertification, speeding it up. As the problem intensifies, the productive capability of the land decreases, destroying the original biodiversity. Different plant species produce physically and chemically different litter compositions in the ground. The litter, along with the natural biologic decomposers in the ground, helps form the soil complex and plays an active role in nutrient cycling. All the vegetation supports the primary production that provides food and wood that works together to sequester carbon, which plays an ultimate role in global climate. When these connections are broken, desertification is triggered and habitats can be jeopardized and lost. Biodiversity loss affects the health of the habitat. Climate change increases evapotranspiration and adversely affects biodiversity.

The loss of vegetation in the food chain impacts life along it. In addition, when native vegetation dies off, invasive species, such as cheat grass (*Bromus tectorum*) in the Southwestern United States, moves in and takes over. Invasive species have a better probability of survival because they lack the native species' predators. It does not take long for invasive species to overrun a landscape, pushing native species out. Once this happens, it may be that only a few invasive species are supported in an area, where at one time dozens of species once existed. In areas where this occurs, the biodiversity is significantly lowered, and unless rehabilitation efforts are put into effect, it may never be able to reestablish itself to a natural, ecologically balanced state. Even if native vegetation is reintroduced, it may not be able to survive if desertification degrades the land to the point where nutrients and water supplies are no longer available.

Biodiversity, which contributes to many of the benefits provided to humans by dryland ecosystems, is greatly diminished by desertification. For example, diversity of vegetation is critical in soil conservation and in the regulation of surface water and local climate. If these delicate balances are disrupted, it can threaten the health and existence of habitats. Desertification affects global climate change through both soil and vegetation losses. Another problem that exists involves the use of land for livestock grazing. When desertification becomes an issue and invasive weeds move into the area, the livestock may consider the new vegetation species unpalatable and refuse to graze.

It is not just one human activity that is responsible for desertification—there are many. Overgrazing of livestock and cultivation are two of the most common reasons, but deforestation is also a major contributor. If groundwater is overused or irrigation of farming areas is not done properly, they can introduce the desertification process. Desertification is also encouraged if soils collect more salt, raising their salinity levels. Climate change is being largely blamed for worldwide desertification in the earth's arid, semiarid, and subhumid areas. This means that desertification is the result of a combination of social, economic, political, physical, and natural factors, which vary from region to region.

Currently, lands that seem to be most prone currently to desertification include the areas at the fringes and outskirts of deserts. These transition areas have fragile, delicately balanced ecosystems, usually operating under various microclimates. Already delicate, once these ecosystems are stressed to their limit of tolerance, they cannot recover on their own. Grazing by livestock is especially harmful because they pack down the soil. The more the subsoil gets packed into an impermeable layer, the less water is able to percolate down into the ground. Because the scarce water is not able to penetrate the ground's subsurface, it flows off the surface, eroding the land with rills and gullies. South Africa, for example, loses 262 million metric tons of topsoil each year. In addition, as the surface dries out, the soil is carried away by the wind.

According to the USGS, there are many things scientists still do not know about desertification of productive lands and the expansion of deserts. To date, there is no consensus among researchers as to the specific causes, extent, or degree of desertification. Desertification is a subtle and complex process.

From a global context, during the past 25 years, satellites have helped scientists study climate change by providing global imagery with which to study the effects of desertification. The existence of satellite imagery, such as LANDSAT, SPOT, Quickbird, and Digital Globe, has made it possible to monitor areas over time and determine the susceptibility of the land to desertification. The problem is a global one. It is predicted that by 2100, that climate change will increase the area of desert climates by 17 percent, meaning more areas at risk of desertification. Worldwide, about 12 million hectares becomes useless for cultivation each year—an area equal to about 87 percent of the area of agricultural land in the United States.

Desertification needs to be monitored and managed as a worldwide effort as climate change intensifies. Like global uplifting, it does not stop at international borders. If it is not controlled, biodiversity will be negatively impacted. Another way desertification contributes to climate change is by allowing the carbon that has been stored in dryland vegetation and soils to be released to the atmosphere as it dries out and dies. This could have significant consequences for global climate.

The relationship between climate change and desertification is not straightforward; its variabilities are extremely complex. The best way to deal with desertification is to prevent it from happening in the first place. The most appropriate way to do this is through proper management at local, regional, and global levels. Besides being environmentally better, prevention is also more cost effective than rehabilitation. The best form of prevention requires a change in the attitudes of those living on, and working with, the land, such as employing sustainable, environmentally friendly agricultural and grazing practices. For areas that have already been degraded, rehabilitation and restoration measures can help to restore lost ecosystems, habitat, and services the drylands originally supplied. One of the most important reasons to avoid desertification is to avoid extreme poverty and hunger—when drylands become too degraded in developing countries, it leaves populations with little access to food and clean water.

According to the Ecosystems and Human Well-being: Desertification Syntheses, which is part of the report published in the 2005 Millennium Assessment, the following actions can be employed to prevent desertification (Corvalan et al., 2005):

- Implementation of a land and water management plan to protect soils from erosion, salinization, and degradation.
- Creation of economic opportunities outside of dryland areas, taking the stress off of drylands.
- Protection of vegetative cover so that it will stabilize the soil underneath and keep it from being eroded by wind and water.
- Becoming involved in alternative livelihoods that do not depend on intensive land use. These types of activities include greenhouse agriculture, tourism, and aquaculture.
- Combining areas of farming and grazing in order to centrally manage natural resources more effectively.
- Empowering local communities to effectively manage their own resources and combining traditional practices with local ones.

In areas where desertification has already become established, it is important to rehabilitate and restore the lands in order for them to return to their previous conditions. Successful restoration must be done at the local level. Several methods are commonly used, such as the following:

- Reintroduction of the original, native species that used to live there.
- Combating erosion through the systematic terracing steep areas so that water does not run down slopes eroding the land's surface.
- Establishing seed banks to ensure that species do not become endangered or extinct. Then when climate conditions exist for the plant to survive, seeds can be planted.
- Enriching the soils with nutrients, making them more fertile and conducive to vegetative growth.
- Planting additional reserves of trees.

THE STRAIGHT FACTS ABOUT DESERTIFICATION

For land managers, it is critical that appropriate, effective, and well-thought-out decisions be made about the land and its resources. The following facts reflect the shocking realities of desertification facing today's world:

- Roughly 3.6 billion hectares of the world's 5.2 billion hectares of dryland used for agriculture has been degraded by erosional processes.
- One out of every six people is directly affected by desertification; this equates to nearly one billion people.
- Desertification has forced many farmers to abandon farming and look for urban employment.
- Each year 51,800 square kilometers of land is destroyed by desertification.
- Desertification affects almost 75 percent of the land in North America.
- Dust from deserts can be blown great distances into cities. Dust has been blown from Africa to Europe and the United States. During the Dust Bowl, it was blown from Oklahoma and out across the Atlantic Ocean.
- Desertification destroys the topsoil of an area, making it unable to grow crops, support livestock, or provide suitable habitat for humans.
- Each year, the planet loses 24 billion tons of topsoil. Over the past two decades, enough has been lost to cover the entire cropland of the United States.
- Climate change can trigger desertification as well as poor land management practices.
- The destruction caused by desertification carries a hefty price tag. More than $40 billion per year in agricultural goods is lost, causing an increase in agricultural prices, negatively impacting the consumer.
- According to a United Nations study, roughly 30 percent of the earth's land is affected by drought. Every day, approximately 33,000 people starve to death.
- Desertification makes the environment more likely to experience wildfires.

Desertification is a condition that can be stopped, but it usually is not brought to the public eye until it is well under way, making rehabilitation of the landscape much more difficult and expensive. If it were brought to the public's attention sooner and not allowed to reach a critical point, it would make recovery more manageable. One way to ensure the success of this is through outreach and public education. By keeping people informed and educated about the results of their behavior on the environment, land degradation can be avoided all together. (Rinkesh, 2016).

According to the IPCC, many deserts will face a decrease in rainfall from 5 to 15 percent. Approximately half of the subhumid and semiarid parts of the southern African region are at moderate-to-high risk of desertification. Since the 1970s in West Africa, the long-term decline in rainfall has caused a 25–35-kilometer southward shift of the Sahelian, Sudanese, and Guinean ecological zones in the second half of the twentieth century (IPCC, 2014b).

The results of drought in the rain forest were that the trees managed fairly well after the first year. In the second year, they sunk their roots deeper in the ground to find moisture and still survived. However, by the third year, the trees began dying. The tallest trees were impacted first. As they toppled to the forest floor, the lower canopies were exposed to the direct sunlight. The forest floor was also exposed to direct sunlight and dried out quickly.

After the end of the third year, the biomass had released more than two-thirds of the stored CO_2 to the atmosphere. Where once the forests operated as a carbon sink, they were now a major carbon source. What has scientists concerned is that the Amazon currently holds about 81.6 billion metric tons of carbon, enough in itself to increase the rate of climate change by 50 percent. On top of that, if a wildfire were to start in these remote locations and destroy the vegetation, the rain forests would be transformed into a desert. Dr. Deborah Clark from the University of Missouri, a renowned forest ecologist, says that the research shows that "the lock has broken" on the Amazon system. "The Amazon is headed in a terrible direction." (Real Climate, 2006)

Heat Waves

Temperatures are obtained from monitoring stations worldwide in order to calculate global mean temperature rise. When temperatures are taken near cities, they must be corrected to eliminate the specific effect that the presence of the urban area has on the temperature reading. Because urban areas have so many dark surfaces—such as asphalt-covered roads and dark roofs on buildings, they absorb more heat than natural surfaces such as grasses, prairies, and woodlands. This absorbed heat is reradiated by the buildings and roads, and the resultant increase in temperature from these sources, as well as heat released from industry, cars, and other sources of burning fossil fuels, adds to the increased temperatures.

In order to use a reliable temperature value instead of a skewed value due to artificial inputs, collectively referred to as the urban heat island effect, this contribution to the temperature must be accounted for and removed. In addition, the various instruments and methods used worldwide must also be calibrated so that the temperatures collected are directly comparable.

In a global temperature analysis conducted by NOAA, they released a report in 2016 stating that 2015 was the warmest year in the 136-year period of record. Specifically, December 2015 was the warmest month in the period of record, at 1.11°C higher than the monthly average, breaking the previous all-time record set two months earlier in October 2015

TABLE 4.4
Sixteen Warmest Years (1880–2015)

Rank (1 = warmest)	Year	Anomaly (°C)	Anomaly (°F)
1	2015	0.90	1.62
2	2014	0.74	1.33
3	2010	0.70	1.22
4	2013	0.66	1.26
5	2005	0.65	1.19
6 (tie)	1998	0.63	1.17
6 (tie)	2009	0.63	1.13
8	2012	0.62	1.12
9 (tie)	2003	0.61	1.12
9 (tie)	2006	0.61	1.10
9 (tie)	2007	0.62	1.10
12 (tie)	2002	0.60	1.10
13 (tie)	2004	0.57	1.01
13 (tie)	2011	0.57	1.08
15	2001	0.54	0.97
15	2008	0.54	0.97

Source: National Oceanic and Atmospheric Administration, 2015.

by 0.12°C. This is the first time in the NOAA record that a monthly temperature departure from average exceeded 1°C (or reached 2°F), and the second widest margin by which an all-time monthly global temperature record had been broken. February 1998 broke the previous of record in March 1990 by 0.13°C. Table 4.4 depicts the 16 warmest years on record from 1880 to 2015 (NOAA, 2015). Figure 4.12 illustrates significant climate anomalies and events from 2015.

Figure 4.12 depicts specific climate anomalies and events from 2015.

The only reliable explanation scientists have been able to come up with this far in their models is human interference. The temperature rises in the models accurately reflect the actual temperature rises the earth has experienced so far when the effects of greenhouse gas levels from the burning of fossil fuels and deforestation are entered into the mathematical model equations. If the human interference factor is not added, the models do not work—they underestimate actual temperatures. The polar latitudes have been identified in models as those areas on earth that are being impacted the fastest and most significantly. In addition, nighttime temperatures have increased much more than daytime temperatures, keeping the earth's atmosphere warmer overall. This is significant because when the earth stays warmer at night, it retains the heat that was generated during the day in the atmosphere, starting the next day off warmer than normal.

The Union of Concerned Scientists believes that by the year 2100 there will be an increase in average surface air temperature of around 2.5°C. The result of this will mean an increase in temperature at many scales, such as days, seasons, and years. When looking at significant local levels of temperature increases, this means that some areas will succumb to more "extremely hot summer days" during the summer and "killer heat waves" will occur (Union of Concerned Scientists, 2007).

As heat wave incidents increase, more people would be negatively affected and many of these could die. The sick, very young, the elderly, and those that cannot afford indoor air conditioning are at the most risk of dying. As an illustration, in 1995 in Chicago, nearly 500 people died during a significant heat wave.

In July and August 1999, another heat wave hit Chicago. Because emergency response network specialists learned some valuable lessons in 1995, they were better prepared for this one. Even though the response was better, 103 heat-related deaths still occurred.

Chicago is not alone. In 1980, a heat wave in the United States killed 1700 people in the East and Midwest, and again in 1988, one killed 454 people. In 1998, more than 120 people died in a Texas heat wave. Europe experienced a deadly heat wave in 2003, so hot in fact; it was considered the hottest summer in 500 years. During this period, 27,000 people died from heat-related problems. Some of those who did not die suffered irreversible brain damage from advanced fevers as a result of the intense temperatures (Environmental Defense Fund, 2011). The heat wave in the United States in 2006 was one of the worst it had ever experienced. It held the entire country in its grip and lasted for almost a month. The effects and costs of these were enormous—hundreds of people died, massive power outages were triggered, and unmanageable wildfires burned large areas of ground. Tens of thousands of people in New York went without electricity for over a week.

One thing that scientists cannot do with the overall issue of climate change is to blame a single weather event—like a heat wave, a hurricane, a blizzard, or a tornado—on climate change, because weather fluctuates naturally. However, what they can relate to are climate change are trends. Based on the fact that climate models predict more wild and unpredictable weather as a future trend, expecting an increase in heat waves does fit into the future climate scenario. One thing that both the developed and developing countries need to be aware of is that continued urbanization will increase the number of people vulnerable to these urban heat islands and heat waves.

Wildfire

The likelihood of a disastrous wildfire occurring increases significantly during periods of drought. The world saw the proof of this in 1997 through 1998 when an El Niño episode caused extremely dry conditions in many areas across the globe. Large forest fires occurred in Brazil, Central America, Florida, eastern Russia, and Indonesia. Wildfires can easily occur during drought periods from both natural and human-caused factors. Lightning strikes, as well as campers or hikers, commonly cause them. Regardless of the cause, during drought conditions, the vegetation is so dry that it does not take much to start a wildfire, and when they start, they burn fast and intense.

Based on a report from the Natural Resources Defense Council, the 2006 wildland fire season set new records in

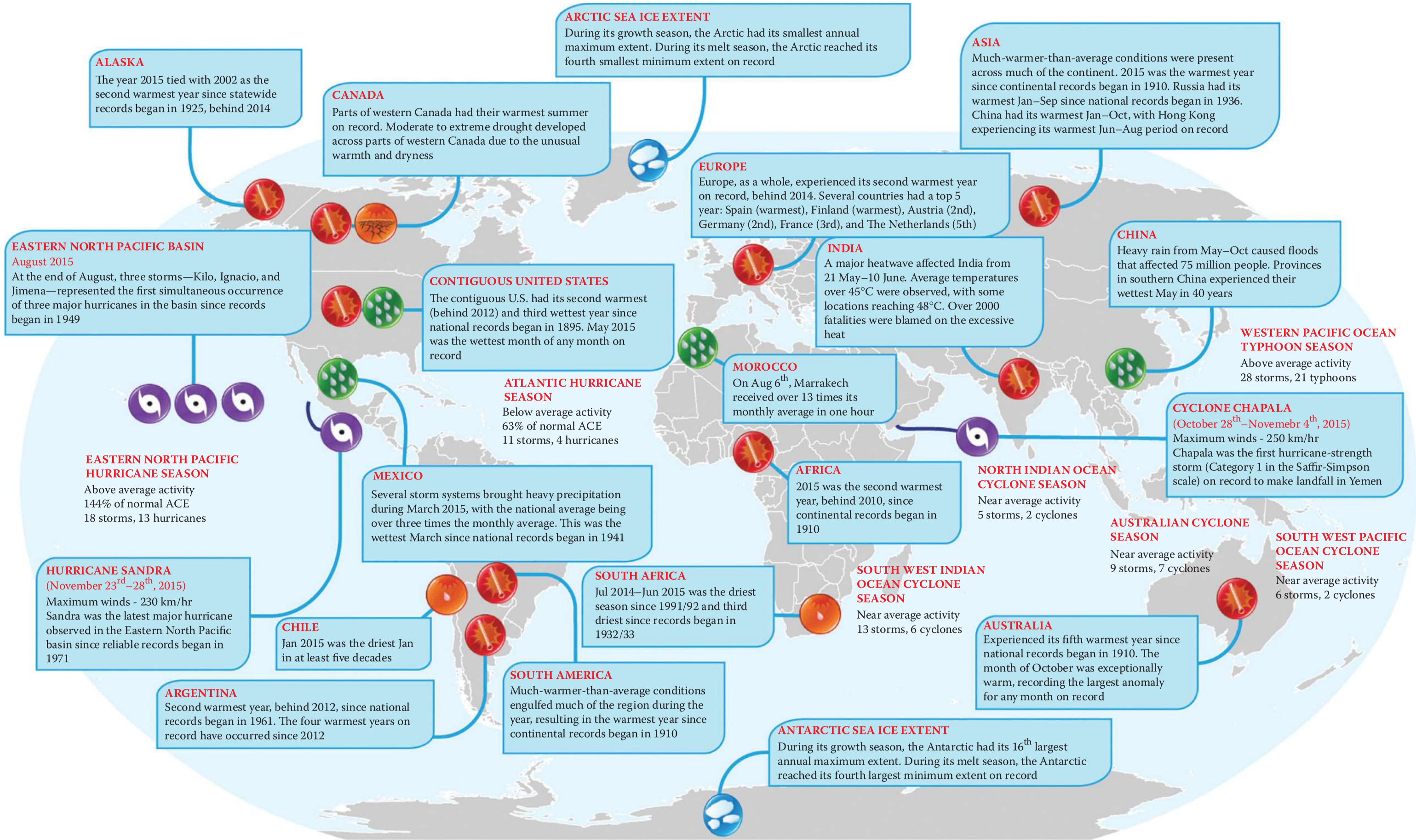


FIGURE 4.12 Significant climate anomalies and events from 2015. (Courtesy of NOAA, Silver Spring, MD.)

both the number of reported fires and the acres burned. Nearly 100,000 fires were reported and nearly 4 million hectares burned—125 percent above the 10-year average. If warming continues to spur wildfire seasons, it could be economically devastating. Fire-fighting expenditures recently have totaled $1 billion per year.

In work done by the Union of Concerned Scientists, they state that "The number of large wildfires—defined as those areas covering more than 1,000 acres—is increasing throughout the Western United States. Over the past 12 years, every state in the West has experienced an increase in the average number of large wildfires per year compared to the annual average from 1980 to 2000".

In addition, the wildfire season, defined as the time period between the year's first and last large wildfires, has also been lengthening. Although it varies from region to region, there is a trend over the entire Western United States of the season extending over the past 40 years. For example, in the early 1970s, the average length of the wildfire season was approximately five months. Currently, it is more than seven months.

Two factors that are contributing to this trend are rising temperatures and earlier snowmelt. Temperatures are increasing much faster in the Western United States than for the earth as a whole. Since 1970, average annual temperatures in the West have increased by 1.05°C, which is about twice the global average increase. Hydrologists have also determined through measurements taken from streamflow gauges in the West that the timing of springtime snowmelt has changed. Although it differs specifically by location, overall the onset of spring snowmelt is occurring 1–4 weeks earlier today than it did in the 1940s. This is significant because spring green-up happens earlier, then as temperatures climb higher during the hot, dry summer months, the vegetation dries out and dies, making conditions extremely vulnerable to wildfire.

Future wildfire projections vary between ecosystems, but higher temperatures are expected to continue to play a critical role in wildfires. The semidesert and desert regions will most likely be hit the hardest, but every type of ecosystem will feel the effects of a warming environment and increased average annual burn area. The only way to keep the vulnerable areas to a minimum will be to lower our emissions of CO_2 (UCS, 2016b). Table 4.5 lists the worst wildfires in the last decade in the United States. All were in the West.

Mountain Ecosystems in Danger Worldwide

Mountain systems are another ecosystem that is vulnerable to the effects of climate change. Adverse effects can be seen via rising temperatures, the melting of glaciers at the higher latitudes, and the earlier disappearance of annual winter snowfalls in the spring. Also significant is the effect that these changes in the mountain regions have in the lowland areas that they are connected to. In particular, climate change in mountain regions can have a significant effect on the wildlife that lives in the region, agriculture, water supplies, and human habitat.

Climate change, coupled with the fact that many mountain ranges generate their own microclimates, presents many challenges to the life that resides on and around them. These conditions often provide for rich habitats for a large variety of organisms and wildlife, adapted specifically to the surrounding environment. For this reason, it also comes with drawbacks in a changing climate. Upsets in ecosystem balance can have a drastic effect on species that have adapted to specific niches, even to the point of threatening their existence. An example of this is the American Pika (*Ochotona princeps*), a species of rabbit that exists in the Rocky Mountain regions. Preferring cool climates, it is very sensitive to climate change. The concern is that as the climate warms, it relocates to higher elevations. At some point, however, it will run out of higher elevations to relocate and adapt to, and will ultimately be threatened with extinction (Figure 4.13).

TABLE 4.5

The Most Destructive Wildfires in the United States, 2006–2016

Date	Location	Area Burned (acres)	Property Lost	Lives Lost
March 2006	Texas	191,000	15 homes 10,000 horses/cows	0
October 2007	Southern California	500,000	1,300 homes	3
September 2010	Colorado	6,181	168 homes	0
September/October 2011	Texas	32,000	1,700 homes	2
May/July 2011	Arizona/New Mexico	538,049	75 structures	0
June/July 2012	Colorado	18,947	346 homes	0
May–July 2012	New Mexico	297,845	0	0
June/July 2012	Colorado	244,000	600+	6
June 2013	Arizona	8,000	0	19
August–October 2013	Yosemite, California	257,314	0	0
July/August 2014	Washington	250,000	300	0
September 2015	California	283,000	1,050	1

Source: (USFS, 2016).

FIGURE 4.13 American pika. (Courtesy of Sevenstar, Wikimedia Commons.)

Globally, the human-contributed greenhouse gas emissions are expected to lead to average worldwide warming of between 1.1°C and 6.4°C from 2000 to 2100. The specific amount of warming will depend on the regions, although it is expected to be greater over land and in high northern latitudes. Areas of snow cover are expected to lessen overall, whereas snowfall may increase in regions with very cold temperatures, such as high mountains. Most glaciers and ice caps will lose mass or disappear over time.

Because mountain environments are so responsive to changing temperatures, mountains are one of the best areas to see evidence of climate change. Many scientists believe that the changes happening in mountain ecosystems right now provide an early glimpse of what could come to pass in lowland environments, and that mountain areas act as an early warning system of what is to come.

Mountains exist in many regions of the world. They also occupy different positions on the globe, as well as differ in shape, extension, altitude, vegetation cover, and climate regime. They will continue to occupy different positions worldwide—altitude, vegetative cover, and climate regime—which means they will be affected differently by climate change. They do share some common features relating to climate change, however. Examples are as follows:

1. Have a unique and complex topography, making their climates variable over short distances. This makes climate modeling of mountainous areas difficult.
2. Because temperature changes with altitude, the impacts of a warmer climate are different for different elevations. The snow line is one of the most variable areas.
3. Mountains act as barriers to wind flow, which can change atmospheric wind flow patterns. These can have an effect on both precipitation amounts and patterns.

Table 4.6 shows regional climate projections for some of the earth's principal mountain regions.

A changing climate's effect on the local agriculture is also of concern in mountain ecosystems, as it plays a significant role on farming and agriculture. In mountainous regions, the major water supply originates from the annual snowmelt from

TABLE 4.6
Regional Climate Projections for Some of the Earth's Principal Mountain Regions

Mountain Range	Projection
The Andes	• Decreased annual precipitation in southern Andes • Other areas' precipitation will depend upon El Niño • Several Andes glaciers may disappear
The Rocky Mountains	• Higher elevations have already experienced a threefold increasing in temperature • Earlier snowmelt in the spring • Shift from snowfall to rainfall • Increased incidence of forest fires
The Hindu Kush-Himalaya	• Warming will be well above the global average • This range plays an important role in climate patterns • Warming will be well above the global average • Models show an increase in precipitation during the winter months
The European Alps	• The Alps have shown a higher than normal warming trend since 1979 • Regional warming is predicted as 1.5 times higher than the average • Precipitation will decrease in summer • Substantial glacier retreat • Duration of snow cover will decrease

Source: From Kohler T. and D. Maselli (eds.), *Mountains and Climate Change—From Understanding to Action*, 3rd ed, Geographica Bernensia, Bern, Switzerland, 2012.

the mountains. In areas that are now experiencing early snowmelt and disappearing glaciers, this significantly affects the soil moisture and agricultural health. As a result of reduced and/or early runoff in the spring the growing seasons often result in low yields because there is no water available when it is needed most during the growing period . In some areas, such as Cotacachi, Ecuador in the Andes, the Cotacahian glacier has been the principal water source that farmers have used to water their crops. Today, it has nearly vanished due to rising temperatures, which means that the rivers in the area are nearly dry. Farmers now have to rely on the sparse rainfall in the area during the growing season, which is unpredictable and has significantly lowered their yields.

Mountain snow and glacial melt also provides drinking water for more than one billion people on earth. As the climate has warmed, this has diminished and these populations have had to change their water consumption habits and survive on lower supplies of water. On average, a home with a constant water supply will use more than 100 liters per person per day. A key goal of mountain environments and future community growth is that these developments will have to adapt to lower water availability. This means that the public will have to be educated to use their water resources responsibly.

Another area to consider is recreation. Businesses, such as ski resorts, depend on winters with above average amounts of snowfall in order to provide the best recreational opportunities for their clients. During years of less snowfall, they feel the negative impacts, not only in the length of the ski season but in its quality. In a warming world, they face the possibility of having to adapt their businesses to something that offers other activities just as important as skiing that can be done with either low amounts or no snow.

Mountain environments are also seeing economic impacts as their water supplies become more strained. As crops fail and livestock herds diminish because the land can no longer support the number of animals it previously could, this translates into serious economic losses. In areas where businesses have shrunk to a certain threshold, people have been forced to relocate to other, more desirable locations. Because each mountain environment is unique, the extent of impact depends on the current climatic and ecological situation, and on the topography of the area (Kohler and Maselli, 2012).

Challenges in Marine Environments

Climate change has a significant effect on the marine environment. It is affecting ocean temperatures, the supply of nutrients, ocean chemistry, food chains, wind systems, ocean currents, and extreme events such as cyclones. These, then affect the distribution, abundance, breeding cycles, and migrations of marine plants and animals that millions of people globally rely on for food and income. Even of more concern is that marine organisms may be responding faster to climate change than land-based plants and animals. As temperatures rise, marine plants and animals are shifting toward the poles. This, in turn, changes the dynamics of food webs and impacts the animals (including people) that depend on them.

Temperate Marine Environments

There are several components of the temperate marine environment that climate change could impact, such as changes in temperature, shoreline ecology, and major storm tracks. Two elements that are the least complicated to predict are temperature and sea-level rise; others are much more complex depending on the scale and degree of interaction between other components in the environment.

It is difficult to use existing climate models to address these issues because they produce outputs that generally depict broader geographical regions than the scales that local storms occur at. Models are not refined enough at this point for their spatial resolution to be able to model areas as small as a specific bay or coast.

According to the IPCC, they predict that by 2100, the earth's near-surface temperature averaged worldwide will increase by 1.4°C–5.8°C from the 1990 levels. This means that sea-surface temperatures will also rise. The IPCC believes that this will be the highest temperature rise seen in the past 10,000 years. The aspect of the temperature rise that will cause the most significant ecological change in estuary and marine ecosystems is the rapid speed with which it is expected to happen, leaving species little time to adapt (IPCC, 2007a).

Based on data from the IPCC, globally averaged sea level rose between 10 and 20 centimeters during the twentieth century. They predict the oceans will rise another 9–88 cm between now and 2100. The rise will be the result of both (1) thermal expansion of the current ocean water (the warmer the temperature, the more water expands) and (2) melting from land-based glaciers and ice sheets.

The Pew Center on Global Climate Change is a nonprofit organization that brings together business leaders, policy makers, scientists, and other experts worldwide to create a new approach to managing the problem of climate change—what they refer to as an extremely "controversial issue." Not slanted in any particular way politically or economically, they "approach the issue objectively and base their research and conclusions on sound science, straight talk, and a belief that experts worldwide can work together to protect the climate while sustaining economic growth (EEA, 2017)."

In January 2007, the Center was one of the inaugural members of the U.S. Climate Action Partnership—an alliance of major businesses and environmental groups that calls on the federal government to enact legislation requiring significant reductions of greenhouse gas emissions. According to the Pew Center, in terms of climate change, the biggest impact on estuarine and marine systems will be temperature change, sea-level rise, the availability of water from precipitation and runoff, wind patterns, and storminess. In these often-fragile systems, temperature has a direct and serious effect. For the sea life living within the ocean, temperature directly affects an organism's biology, such as birth, reproduction, growth, behavior, and death.

Temperature differences can also influence the interaction between species, such as predator–prey, parasite–host, and other competitions that may develop over the struggle for limited resources. If temperatures change the distribution patterns of organisms, it could also change the balance of predators, prey, parasites, and competitors in an ecosystem, completely readjusting balances, food chains, behaviors, and the equilibrium of the ecosystem.

Climate change can also change the way that species interact by changing the timing of physiological events. One of the key changes that it could alter is the timing of reproduction for many species. Rising temperature could interfere with the timing of the birth being correlated with the availability of food for that species. This can be a problem, for example, for bird species that migrate and depend on a specific food source to be available when they reach their breeding grounds. If warmer temperatures have changed the timing a few weeks of when the food will be available, and it is not synchronized anymore with the migrating birds, it could leave the birds without available food, threatening their survival.

Sea-Level Rise

Melting glacial and polar land ice will add to sea-level rise. The effects of sea-level rise will not be constant but will vary with location, how fast the sea level rises, and the biogeochemical responses of the individual ecosystems involved. The South Atlantic and the Gulf of Mexico have been identified as susceptible areas.

As sea levels rise, ocean water will submerge and erode the shorelines. In natural areas covered with marshes and mangroves, as sea level rises, it will flood the wetlands and waterlog the soils. Because the plants that live in the wetlands, which do not contain salty water, are not accustomed to salt, the salty ocean water would kill them. Because wetlands provide habitat for wildlife, including several migrating birds, this would also destroy their habitat.

The areas that would be hard hit are those that cannot migrate inland because urbanization has been built right up to the shoreline, effectively removing any possible potential wetland habitat. This presents a serious impact to the environment because wetlands are an important part of the biological productivity of coastal systems. Marshes provide many critical services; they function not only as habitats for wildlife but as nurseries for breeding and raising young, and as refuges from predators. Wetlands function as part of an integrated system. If they are jeopardized, their loss will affect the availability and transfer of nutrients, the flow of energy, and the availability of natural habitat needed by the multitudes of organisms already living there. One of the most unfortunate losses will be those areas where rare, threatened, or endangered plant and animal species live, such as the American alligator (*Alligator mississippiensis*), Florida black bear (*Ursus americanus floridanus*), West Indian manatee (*Trichechus manatus*), Florida panther (*Puma concolor coryi*), Southern bald eagle (*Haliaeetus leucocephalus*), snowy egret (*Egretta thula*), and roseate spoonbill (*Platalea ajaja*). If invading salt water destroys these habitats, they could become extinct.

Because the oceans are so vast, most of the predictions made about the earth's open oceans in light of climate change have been generated by computer models. The two most important functions that govern the behavior of the ocean are temperature and circulation, and these calculations are fairly straightforward in computer models and readily calculable. Another thing that makes it possible to model the oceans using computers is that human impact has not had as large an impact on the oceans as it has on the land.

Tropical Marine Environments

The world's tropical and subtropical marine environments represent some of the most diverse habitats on earth. Often characterized by reef-building corals, the complex arrays of marine inhabitants that occupy these waters have developed many strategies for survival. Their ecosystems are so complex that a delicate balance is needed to protect these numerous marine resources, while also accommodating an economy centered on commercial fisheries and recreation.

The tropical marine environment is also subjected to many of the environmental concerns as the temperate marine environment, such as temperature, sea-level rise, wind circulation, and algal blooms. An additional risk the tropical habitat encounters is the negative impact on reefs and corals. These ecosystems represent some of the most fragile on the earth and some of the hardest hit with the negative effects of climate change.

Fragile Ecosystems—Reefs and Corals

As climate change causes the earth's tropical oceans to heat up, they become more acidic, and strong storms become more common, the world's coral reefs are taking a beating. Rod Fujita of the Environmental Defense says, "Coral reefs may prove to be the first ecological victims of unchecked global warming." (EDF, 2007b).

Loss of coral reefs would translate into huge economic losses in coastal regions dependent on reefs. They currently provide about $30 billion each year in goods and services (Harvey, 2016).

Destruction of reef systems also represents an ecological disaster. Coral reefs are sometimes referred to as the rainforests of the ocean because they provide habitat to a rich diversity of marine life, including reef fish, turtles, sharks, lobsters, anemones, sponges, shrimp, sea stars, sea horse, and eels. Reefs attract scuba divers from around the world each year to swim among the beautiful, otherworldly shapes and color combinations. Corals actually obtain their food and color from tiny algae called zooxanthellae that live in them. They have a very narrow temperature tolerance range. In fact, if the water increases only 1.1°C above the typical maximum summer temperature, it can cause corals to expel their algae and turn white, through a process called "bleaching." If bleaching continues for a prolonged period of time, the corals will die.

Currently, 93 percent of the reefs of the Great Barrier Reef of Australia have been affected by coral bleaching due to the abnormally warm ocean temperatures accompanying climate change. Since 1998, there have been three mass bleaching events documented, and the effects have been devastating. A major contributor to the situation is the warm water flowing around the Pacific Ocean caused by El Niño events along with the warming caused by the presence of greenhouse gas emissions. Because corals bleach when they are subjected to temperatures above their normal summer maximum for at least a month (usually combined with few clouds and high levels of ultraviolet radiation), they become subjected to bleaching. Over this time interval, of a total of 911 individual reefs that make up the Great Barrier Reef complex, only 68 have not been entirely bleached. More than half have been severely bleached and 81 percent in the northernmost reaches have experienced severe bleaching. Professor Terry Hughes of James Cook University and head of the National Coral Bleaching taskforce stated, "We've never seen anything like this scale of bleaching before. In the northern Great Barrier Reef, it's like ten cyclones have come ashore all at once." Unfortunately, if coral remains bleached for a long time, it dies. Presently, the northern portion of the reef is seeing over a 50 percent mortality rate and it is expected that some reefs will exceed a 90 percent mortality (Slezak, 2016).

World Wildlife Fund has identified both the Seychelles Islands and American Samoa as locations under high stress for coral bleaching. The United Nations Educational, Scientific, and Cultural Organization recognize the Seychelles Islands as a natural World Heritage Site. They have a high coral diversity and support rare land species, such as the giant tortoise. In addition to increase ocean temperatures, these areas are also threatened by climate change because of more frequent tropical storms (which could break up the coral) and more frequent rains, flooding, and river runoff (which deposits sediments in the ocean) (WWF, 2011) (Figure 4.14).

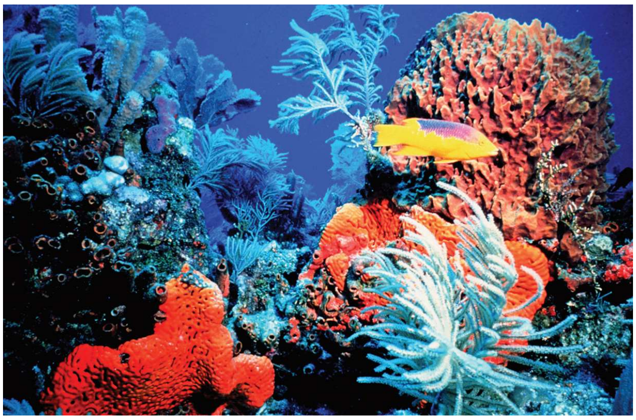


FIGURE 4.14 Coral reefs are often referred to as the rain forests of the ocean because they provide habitat for an extremely diverse collection of life forms. Climate change is threatening their existence. (Courtesy of NOAA, Silver Spring, MD.)

OUR FRAGILE REEF SYSTEMS

The Union of Concerned Scientists has determined the following:

- Australia's Great Barrier Reef—the world's largest coral reef—is a unique marine ecosystem threatened by climate change. Damage to the reef could harm the region's biodiversity, tourism, and fisheries.
- The reef has suffered eight mass coral bleaching events since 1979, triggered by unusually high water temperatures. If there is enough time between bleaching events, the coral can often recover. However, annual bleaching is expected by the mid-century if our heat-trapping emissions continue at their current pace, thus leaving the reef vulnerable to diseases from which it may not recover.
- Ocean acidification expected to occur if atmospheric carbon dioxide surpasses 500 parts per million is likely to limit the capacity of the reef to recover from bleaching events and to cope with other stresses.
- Scientists project a significant loss of biodiversity within a decade and at worst a 95 percent decrease in the distribution of Great Barrier Reef species by late this century.

Source: UCS, 2016b.

Freshwater Environments

Climate change is also affecting the planet's freshwater ecosystems, such as rivers, lakes, and wetlands. Observable changes include the following:

- An increase in the surface water temperature of lakes and streams, most notably those located in the high altitudes and latitudes
- An increase in the temperature of the hypolimnion layer of large deep lakes
- A reduction in lake ice cover
- Changes in mountain streams due to the melting of glaciers and permafrost, adding pollutants and solutes to surface waters

Given present trends, it is expect that not only will they continue, but the following is also likely:

- The flow in rivers and streams will change depending on the amount, intensity, seasonality, and distribution of precipitation. As temperatures climb, additional melt will cause increased flow, which will increase the transport of sediments and nutrients downstream into lakes and coastal zones.

- Water levels, habitat composition, and water residence times in wetlands will be affected with changes in precipitation, evaporation, and flooding as temperatures warm.
- Intermittent streams and small lakes in warm, dry areas may dry up and disappear. Flow in permanent streams may become intermittent, and permanent lakes may shrink and become more saline.
- Systems existing on the borderline between two conditions may become so unstable; they will abruptly degrade to the less healthy system.

There are several ecological consequences of climate change for freshwater ecosystems. The impacts that a particular ecosystem will experience will be a combination of the local stressors the region is already experiencing, combined with the effects of the changing climate. For example, a river, a lake, or a wetland ecosystem may already be subject to conditions such as acidification, input of toxic substances, hydromorphological changes, catchment land-use change, water resource management decisions, acidification, eutrophication, and invasion of exotic species. In addition to these various inputs, a specific ecosystem may also have to account for colder, temperate/warm-humid, or warm-arid climate changes to the ecosystem (EEA, 2012).

Depending on what conditional climate input existed, it would produce a different ecosystem. For instance, for cold regions, it is predicted that

- There will be an increase in primary productivity in response to the longer length of the growing season and an increase in nutrient release from catchment soils.
- Population decline or loss of colder species will occur as temperatures get warmer.

In temperate, warm-humid freshwater regions, it is expected that

- Eutrophication will be a problem.
- Temperature and nutrient balance will be harder to maintain.
- Areas with higher temperatures will have more intense algal blooms.
- Longer periods of stratification and greater oxygen depletion and increased release of phosphorus from sediments will modify the distribution of species across ecoregions.
- Species will become more susceptible to invasive species invasion.
- Overall biodiversity reduction may lead to impaired ecosystem services.

In warm-arid regions, changes in moisture balance are expected to have negative consequences for freshwater environments. Increased temperatures along with reduced precipitation are expected to cause a loss of habitat as well as changes in community composition due to a decrease in lake levels, less river flow, and increased eutrophication. All of these ecosystem changes will require both economic and ecological adaptive measures at the local scale.

Summing It All Up

In an article published in *The Washington Post* on August 2, 2016, it stated that 2015 was the warmest year on record for earth. It was all documented in NOAA's 300-page report along with scores of other facts and information denoting the severity of 2015's climate. Titled, "State of the Climate in 2015," this notable report was authored by more than 450 scientists from 62 countries worldwide. *Every* single indicator of temperature described in the report leaves *no doubt* as to the severity of 2015's surface temperature: it far exceeded any previous years' value. It was accompanied by a record-notable El Niño—where warmer than normal tropical Pacific Ocean water also contributed to the atmospheric heat (Samenow, 2016). The article summed up the 10 most important findings of the report. They are as follows:

1. The global temperature was the highest on record: the previous record was set in 2014.
2. The average ocean surface temperature was the warmest on record: the average temperature was 0.33°C–0.39°C above average and was responsible for fueling global tropical cyclone activity.
3. Upper ocean heat content was highest on record: This refers to the upper ocean layer and was supported by five different datasets.
4. Global sea level was highest on record: oceans expand as they warm, and melting ice adds to the level. Sea level was about 6.99 centimeters higher than the 1993 average.
5. The El Niño event was one of the strongest on record: it was involved in elevating global temperatures, raising sea levels, and intensifying tropical cyclone activity, and led to droughts, wildfires, and the release of CO_2.
6. Greenhouse gases were the highest on record: for the first time, the level surpassed 400 ppm in the modern record. Methane and nitrous oxide also set record highs.
7. There were a record number of major tropical cyclones in the Northern Hemisphere: a total of 31 major tropical cyclones developed in the Northern Hemisphere (the previous record in 2004 was 23). Of these, 26 reached category 4 or 5—another record.
8. Arctic sea ice had its lowest maximum extent: in February 2015, the maximum sea ice extent was 7 percent below the 1981–2010 average and smallest on record.
9. Glaciers continued shrinking: 2015 was the 36th straight year of global alpine glacier retreat.
10. Extreme temperatures were the most extreme on record: 2015 had the most warm days and warm nights in western North America, Central Europe, and Central Asia. It also had the fewest number of unusually cool days on record (Samenow, 2016).

CONCLUSIONS

As evidenced from the impacts currently happening to ecosystems worldwide, the effects are not minor, nor are they localized. On the contrary, they are serious, large-scale impacts that have endangered species, degraded living conditions, destroyed habitats, impacted the health and livelihood of societies, caused starvation and extensive misery, and threatened the future of both humans and wildlife.

So far.

Yet, step back and reflect a bit.

Scientists have been warning policy makers for the past two decades of the changes humans are making to the environment—changes largely due to lifestyle preferences. And only recently has the political community been listening—Europe for the past decade has been on board, but countries such as the United States have stubbornly turned their heads the other way in almost defiant response—instead demanding that the rest of the world cut back their greenhouse gas emissions while they do nothing.

And the temperatures and parts per million carbon content in the atmosphere have just begun to rise toward what climate scientists predicted a decade ago; with a delayed response time in the Earth's atmosphere, just as they warned.

It is coming down just like clockwork.

What do you suppose it will be like when the temperature climbs another degree? Or two? What about the people in distant, undeveloped countries that never even contributed significantly to the problem that may be suffering the most, while people in developed countries are still trying to live the "business as usual" lifestyle?

Sometimes, it takes the voices of the people, who can listen to the truth, read the facts, and take a good look around their environment—and I am referring to our global environment here—to take the real lead in order to make a real difference. We all have personal choices to make—and that includes the way we treat the environment. The damage being done right now to the earth's ecosystem is oftentimes irreversible and what our direct or indirect actions are causing to be lost will not only impact those of us that inhabit the earth right now but will also impact our children and grandchildren. And for all those future generations who did not have a say and have not seen the beauty yet that this planet has to offer, the time to act is now.

REFERENCES

AMEG (Arctic Methane Emergency Group). 2016. Impacts of the rapidly changing Arctic. http://ameg.me/index.php/impact (accessed August 20, 2016).

Borgen Project. 2014. Top ten poverty in Africa facts. http://borgen-project.org/10-quick-facts-about-poverty-in-africa/ (accessed August 20, 2016).

CarbonBrief. March 28, 2014. Arctic sea ice melt: A story of winners and losers, IPCC scientist says. https://www.carbonbrief.org/arctic-sea-ice-melt-a-story-of-winners-and-losers-ipcc-scientist-says (accessed August 3, 2016).

Conant, R. T. 2010. Challenges and opportunities for carbon sequestration in grassland systems: A technical report on grassland management. *Integrated Crop Management* 9:67.

Conserve Energy Future. 2016. Deforestation facts. http://www.conserve-energy-future.com/various-deforestation-facts.php (accessed August 20, 2016).

Corvalan, C., S. Hales, and S. Hales. 2005. Ecosystems and human well-being (accessed March 27, 2011).

EDF (Environmental Defense Fund). 2011. Deadly heat waves more likely. Environmental Defense Fund. http://www.fightglobalwarming.com/page.cfm?tagID=251 (accessed March 21, 2011).

EDF. August 16, 2007a. Mother nature signals climate warnings. http://www.edf.org/article.cfm?contentID=4823 (accessed March 11, 2011).

EDF. August 16, 2007b. Threats: Coral reef bleaching. http://www.edf.org/article.cfm?contentID=4709 (accessed February 22, 2011).

EEA (European Environment Agency). November 21, 2012. Climate change, impacts, and vulnerability in Europe 2012. EEA Report No. 12/2012. http://www.eea.europa.eu/publications/climate-impacts-and-vulnerability-2012 (accessed August 21, 2016).

Environmental and Energy Study Institute. January 5, 2007. Amazon could become grassland under climate change. *Climate Change News*. http://www.eesi.org/ccn?page=199 (accessed September 21, 2010).

European Environment Agency. 2017. Pew Center on global climate change. https://www.eea.europa.eu/themes/climate/links/physical-science-on-climate/pew-center (accessed May 16, 2017).

FAO. 2010 Global Forest Resources Assessment 2010. Main Report. FAO Forestry Paper 163. Rome. http://www.fao.org/docrep/013/i1757e/i1757e00.htm (accessed May 17, 2017).

Food, fibre and forest products. Impacts, Adaptation, and Vulnerability: Working Group II, 275-303. https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter5.pdf (accessed May 17, 2017).

Harvey, M. 2016. Coral reefs: Importance. http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/coral_importance/ (accessed August 21, 2016).

IPCC. 2007a. *WG1: The Physical Science Basis*. Cambridge: Cambridge University Press.

IPCC, Food, fibre and forest products. *Impacts, Adaptation, and Vulnerability: Working Group II*, 275-303. https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter5.pdf (accessed May 17, 2017).

IPCC. 2014a. Climate change 2014 synthesis report summary for policymakers. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (accessed May 15, 2017).

IPCC. 2014b. IPCC climate change 2013—The physical change basis. http://www.cambridge.org/us/academic/subjects/earth-and-environmental-science/climatology-and-climate-change/climate-change-2013-physical-science-basis-working-group-i-contribution-fifth-assessment-report-intergovernmental-panel-climate-change?format=PB&isbn=9781107661820 (accessed August 2, 2016).

IPCC. 2016. IPCC fifth assessment report. Special report on climate change and oceans and the cryosphere (SROCC). http://www.ipcc.ch/index.htm (accessed August 2, 2016).

Kerr, P. 2009. Dare we celebrate? It's an early spring again. *ISA Ontario*. http://www.isaontario.com/content/dare-we-celebrate-its-early-spring-again (accessed August 3, 2016).

Kohler, T. and D. Maselli (eds.). 2012. *Mountains and Climate Change—From Understanding to Action*, 3rd ed. Bern, Switzerland: Geographica Bernensia.