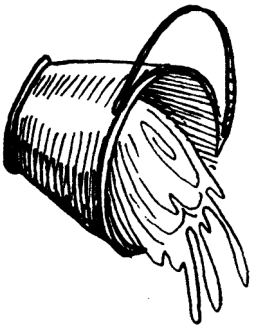
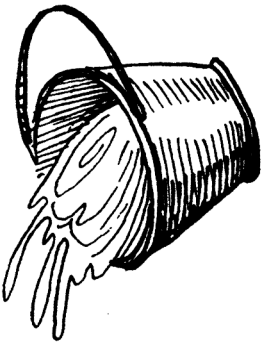
Chapter 3

Climate Change: The Consequences

Many of the consequences of enhanced global warming and climate change have been highlighted and discussed throughout the media, in television programs and newscasts, magazines and newspapers, radio broadcasts, blogs, Websites, and textbooks. The topic is probably the most widely publicized of any current environmental issue. Depending on the source of the information, and the particular bias of the author, some consequences have been downplayed while others have been sensationalized and exaggerated.



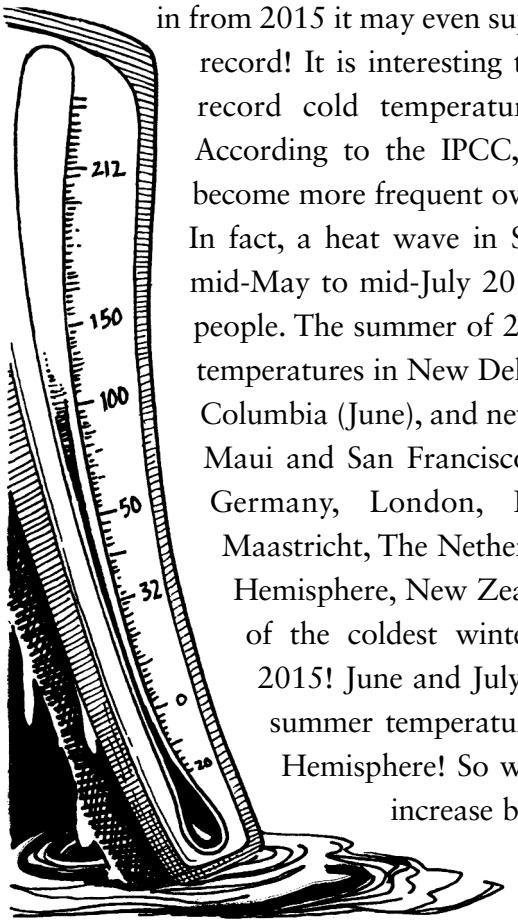


What do we know is happening now, and what could possibly occur in the future? It is clear that we are already seeing global environmental changes that are a direct result of enhanced global warming and climate change. What is unclear is the extent to which these changes may continue to occur, and the impact of other changes that are predicted to take place as a result of the ongoing warming trend. Of course, the extent of any or all of the consequences will depend on how quickly the issue of greenhouse gas emissions is addressed on a global scale. More rapid action will reduce these potential outcomes, while slower action will only lead to a worsening effect. The latest report from the IPCC clearly outlines some of the potential consequences of global warming, and these conclusions have been subject to the highest level of scientific scrutiny and consensus, with over 97 percent of climate scientists in agreement with the findings. So what is the current state of affairs according to the latest IPCC report?

The Temperature Is Rising

The Earth is getting warmer. We are witnessing some of the hottest years on record since the mid-1800s. The effect is global in nature with the land masses experiencing a faster increase in temperature than the oceans. The warming effect is also more pronounced farther

north from the equator. The IPCC suggests that the 30-year time period from 1983 to 2012 could represent the highest temperature change in any 30-year time period in the last 1400 years. In fact, 13 out of the 15 warmest years on record have occurred since 2000. The temperature increase is behind the heat waves that have led to many deaths worldwide, such as the tens of thousands that occurred in Europe during the summer of 2003. In the United States and elsewhere it seems that each year the daily temperature record for many locations is broken. The new ones that are set sometimes end up being broken again in a short time period. In January 2015, both NASA and NOAA jointly released their global temperature data showing that 2014 was the hottest year on record to date, surpassing both the 2005 and 2010 records, marking a 38-year trend of consecutive years with above average global temperatures. When the data is in from 2015 it may even supersede 2014 as the hottest year on record! It is interesting to note that the last time a global record cold temperature was set was back in 1911. According to the IPCC, it is likely that heat waves will become more frequent over most of the earth's land masses. In fact, a heat wave in Southern Pakistan and India from mid-May to mid-July 2015 resulted in the deaths of 3,200 people. The summer of 2015 saw new national record high temperatures in New Delhi, India (May), Vancouver, British Columbia (June), and new July records were set in Kahului, Maui and San Francisco, USA, Madrid, Spain, Kitzingen, Germany, London, England, Melun, France, and Maastricht, The Netherlands. Conversely, in the Southern Hemisphere, New Zealand and Australia recorded some of the coldest winter temperatures ever during July 2015! June and July of 2015 saw the highest monthly summer temperatures ever recorded in the Northern Hemisphere! So what else is this global temperature increase bringing about?



A Global Meltdown

Snow cover on mountain ranges is decreasing. Sea ice in the Arctic and Antarctic is melting at rates even faster than some of the climate models once estimated. Ice on land masses such as Greenland and the Antarctic is melting, and glaciers are receding. Specific examples of this global meltdown include:

- ice caves in Cascades National Park, Washington
- snow cover on mountain peaks in China (Meili Snow Mountain) and Tanzania (Mount Kilimanjaro), and
- glaciers in the Himalayas (Chhota Shigri), Iceland (Breidamerkurjokull), the Swiss Alps (Tschierva), Patagonia (Upsala and Perito Moreno), Canada (Athabasca), and the United States (Boulder in Glacier National Park, Montana, and Muir and Riggs in Alaska).

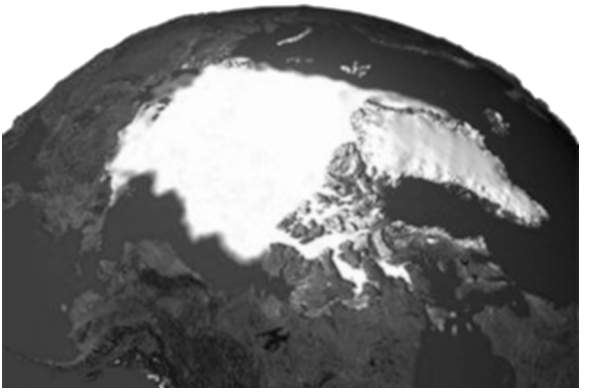
Muir and Riggs glaciers, Alaska in 1941 (Photo: William Field USGS)

Riggs Glacier, Alaska 2004 (Muir Glacier has melted) (Photo: Bruce Molnia USGS)

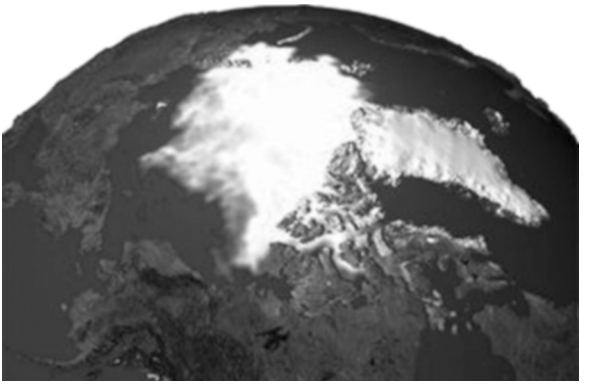
> "Almost all of the mountain glaciers in the world are now melting, many of them quite rapidly."
> —Al Gore in the film *An Inconvenient Truth*

This melting has caused an increase in the size of glacial lakes in mountainous regions, and altered the flow in glacial and snow-fed streams and rivers. People in many parts of the world are dependent on snowmelt from mountain ranges as their predominant source of drinking water. Changes in the flow rates of glacial and snow-fed rivers will ultimately create water shortages for those populations who are dependent upon them. The Rockies supply Los Angeles and Southern California; the Himalayas supply Northern India.

Melting of sea ice has been observed in both the Northern and Southern hemispheres. In the Arctic the ice cover is shrinking, and according to the IPCC the extent of Arctic sea ice may decrease by 20 percent by 2050 with some summers to be completely ice-free by that time.



Arctic ice cap in late summer, 1979 (Photo: NASA)

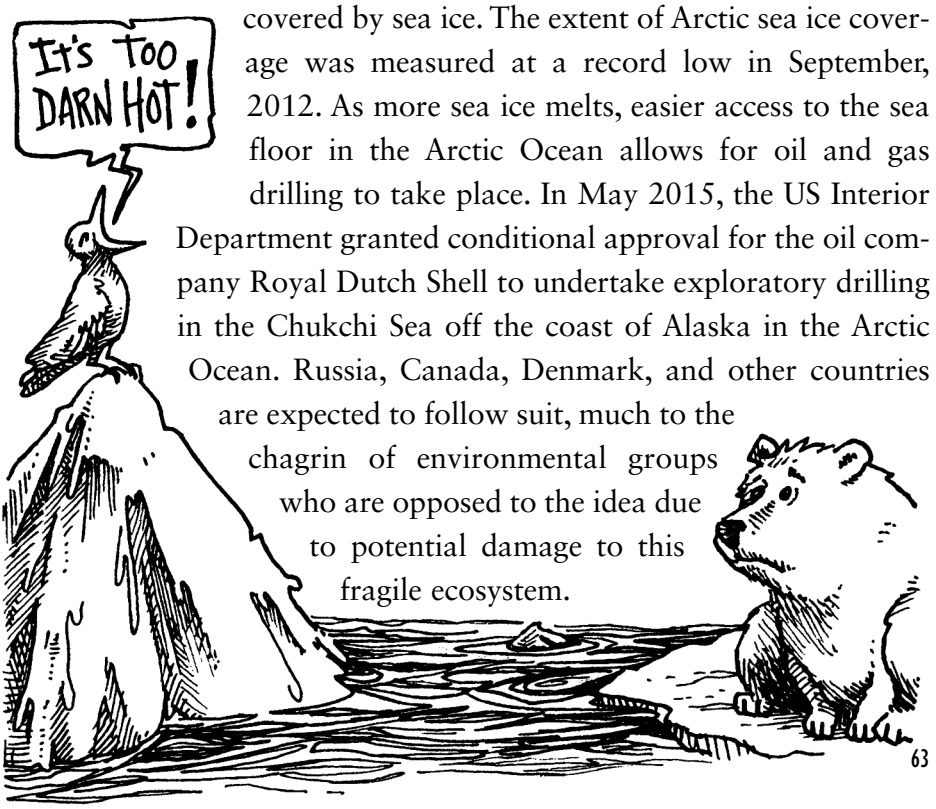


Arctic ice cap in late summer, 2003 (Photo: NASA)

Dr. Donald Perovich is one of the lead research scientists on the Seasonal Ice Zone Network project, which measures the thickness and melting speeds of Arctic ice. Based at the US government's Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire, Perovich refers to the Arctic as "the canary in the coal mine" of enhanced global warming. He points out that in 1982 the permanent Arctic sea ice covered an area about the size of the continental United States.

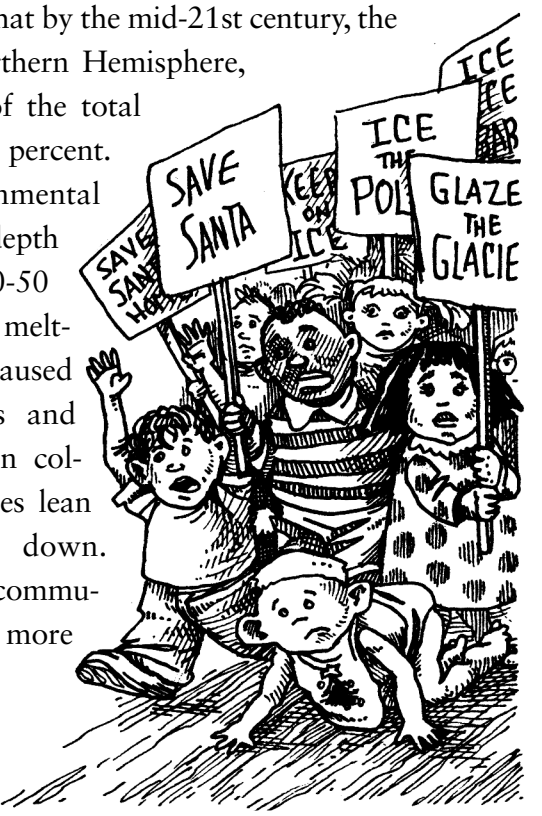
In 2005, the permanent ice cover had decreased by an area roughly the size of the 22 states east of the Mississippi River. "The only way you can get that much melting is by the human component," Perovich commented in July 2007. Of course the melting of the Arctic sea ice could open up the historically sought after Northwest Passage, which Perovich says would provide "a shortcut across the top of the world." The impact of this increased shipping on marine ecosystems is the subject of an ongoing study by the CRREL scientists.

The sea ice in the Arctic does not cover any land mass; it is simply a large amount of ice that floats on the upper region of the ocean. The melting of the sea ice directly affects planetary *albedo,* the amount of sunlight that is reflected back into outer space. Sunlight is reflected from the surface of the ice back into space. As the ice melts, less sunlight will be reflected and more of the sun's energy will be absorbed by the darker surface of the water. This will cause the temperature of the surface water to increase which will in turn lead to the melting of more ice. A positive feedback loop will have been established and over time less of the Arctic region will be covered by sea ice. The extent of Arctic sea ice coverage was measured at a record low in September, 2012. As more sea ice melts, easier access to the sea floor in the Arctic Ocean allows for oil and gas drilling to take place. In May 2015, the US Interior Department granted conditional approval for the oil company Royal Dutch Shell to undertake exploratory drilling in the Chukchi Sea off the coast of Alaska in the Arctic Ocean. Russia, Canada, Denmark, and other countries are expected to follow suit, much to the chagrin of environmental groups who are opposed to the idea due to potential damage to this fragile ecosystem.



Ecologists are concerned about what will happen to polar bear populations should the Arctic ice continue to melt and disappear at its current rate, but younger folk have their own worries—one day the North Pole will no longer be frozen and will no longer provide a home for the jolly old elf in the red suit! Where will Santa Claus relocate when the North Pole melts? Children all over the world look forward to his annual visit in return for being "nice" all year. Will Santa have to relocate to the South Pole as a result of global warming? I know many children who are very alarmed about the possibility of the North Pole melting. Will the reindeers drown or will they fly off in time? To these children this is a real concern. Perhaps in the future we shall witness a Million Toddler March in capital cities around the world, children carrying placards with SAVE SANTA'S HOME.

Not only is the warming in the Arctic causing the sea ice to melt, it is also having an impact on the permafrost in the tundra. Changes in these permafrost areas usually take place over centuries, but are now being observed over a human lifetime. For example, as recently as 35 or 40 years ago the tundra was frozen for more than 230 days a year; today some parts of the tundra were frozen for just 75 or 80 days. The IPCC estimates that that by the mid-21st century, the area of permafrost in the Northern Hemisphere, which comprises 24 percent of the total land mass, will decline by 20-35 percent. The United Nations Environmental Programme predicts that the depth of thawing could increase by 30-50 percent by the year 2080. The melting permafrost in Alaska has caused land subsidence. Foundations and building walls crack, and even collapse. Telephone poles and trees lean over and eventually fall down. Shishmaref, an Alaskan island community, has been inhabited for more



than four centuries. The permafrost is melting and buildings have become unsafe, causing some of the residents to contemplate evacuation from their homes or the abandonment of the whole community. As the permafrost melts, it releases trapped carbon dioxide and methane once locked up in the frozen ice.

Another example of a positive feedback loop on global warming: increased Arctic temperatures cause melting permafrost which releases carbon dioxide and methane which brings about increased Arctic temperature causing . . .

Near the other pole, an alarming event took place between late January and early March in 2002. Antarctica's Larsen B ice shelf broke up at rate that had never been witnessed before. In May 2015, NASA reported that this 10,000 year old ice shelf will disappear by 2020. It is only a matter of time before the Larsen C ice shelf begins to break up. This 150,000 year old ice shelf, about the size of Scotland, already has a giant crack in its surface. The ice shelves in the Antarctic hold back the glaciers that cover the land mass. When the ice shelves break up, they no longer hold back the land-based glaciers. The "land ice" falls into the sea and more dire consequences can then take place.

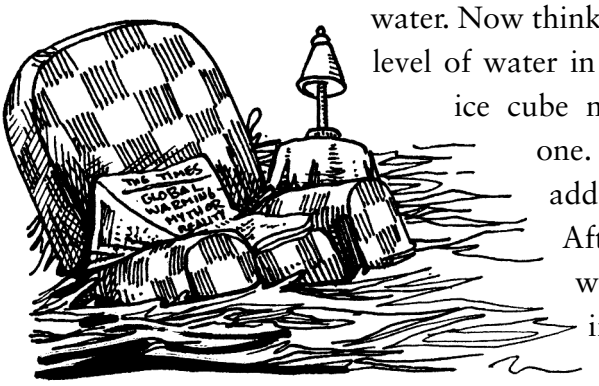
Rising Sea Levels

As ice melts it can bring about a rise in sea levels worldwide. Water has many unique properties; one of them is that as it freezes it expands. Have you ever known anyone to suffer from burst water pipes in the winter? As the water becomes ice, it passes through a temperature where its volume increases and the pressure exerted on the pipes is strong enough to break them. When the ice becomes liquid the

pipes leak as the water flows freely from them through the break. As the sea ice, icebergs, and ice shelves melt the global sea level will increase due to this thermal expansion of water. According to the IPCC, since 1993 sea levels have been rising at around 3.1 mm per year, a finding consistent with the enhanced global warming trend. The global mean sea level rose by around 0.19 m (about 7.5 inches) from 1901-2010. The melting water from the sea ice was part of the ocean before it froze, so when it melts the impact on sea level rise will not be as great as from ice that melts from land masses that comes mainly from precipitation.

The melting of land-based ice in glaciated areas such as Greenland, Antarctica, and snow-covered mountain peaks will have a far greater impact on global sea levels than the melting of sea ice. The glacial ice in Greenland is melting at such a rapid rate that it could result in extremely high sea levels, simply by adding water to the ocean. *Chasing Ice*, the award-winning documentary on climate change by National Geographic photographer James Balog and his team on the Extreme Ice Survey, clearly shows the rapid melting of the glaciers in Greenland and other parts of the world. Scientists estimate that if all the ice covering Greenland were to melt, it could raise sea levels by 21 feet worldwide!

Think of it like this—if you put an ice cube in a glass of water and measured the level of water in the glass, then let the ice cube melt and measured the level of water again, it will have gone up by a very little bit, so small that it may be hard to see. This is like what happens if sea ice or icebergs melt that are already floating in the water. Now think what would happen to the level of water in the glass if every time the ice cube melted you added another one. When that one melted you added another one and so on. After a while the level of water in the glass would increase, and eventually



water would spill over the rim. If the land ice in glaciers, or the runoff from the snow melt from mountaintops, is added to the ocean the level will keep rising as more ice, or runoff, is added. Glaciers breaking off land masses such as Greenland and the Antarctic and falling into the ocean have a major impact on sea level rise. Think of what happens when a garden pond freezes in winter and then melts in spring. The level of water does not change much, because the ice on top of the pond is part of the water that was already in the pond. If during the winter when the pond was frozen you dumped a truckload of ice cubes onto the frozen surface of the pond, when the thaw came the water level would be higher as a result of the extra water that was added to the pond ecosystem.

It is the melting of this land-based ice that is really worrying climatologists. But why? If we had more water in the seas and oceans, there would be a bigger area for marine species, right? Yes, but rising sea level has other consequences that may offset any ecological benefits. Roughly half of the earth's human population lives in coastal areas; the potential effects of sea-level rise could be devastating and widespread. Low-lying coastal plains would become flooded and submerged by the advancing seas. Homes that were on the coast will become submerged. Homes that were miles inland will become, for a while, homes by the sea until the sea advances past them and they become submerged as well. This scenario is not too far-fetched. On July 23, 2015, James Hansen and a group of 16 of the world's leading climate scientists published a must-read discussion paper on the subject of ice melt, sea level rise, and superstorms. They state that the rise in sea level may be as much as 10 feet in the next 50 years, and even more after that time. In a discussion with the host of CNN's *Fareed Zakaria GPS* the following Sunday morning Hansen, an Adjunct Professor at Columbia University's Earth Institute, stated that "science is telling us we have an emergency that could wreak havoc on all of the coastal cities around the world." When asked by Zakaria about what should be done about it, Hansen replied "we're going to have to reduce emissions as fast as practical." When asked about how the

skeptics would view the publication, Hansen acknowledged "That's the nature of science. That's the lifeblood of science. You always are skeptical of any new conclusion." Perhaps the residents of Washington, DC do not realize that they live in what could become oceanfront property!

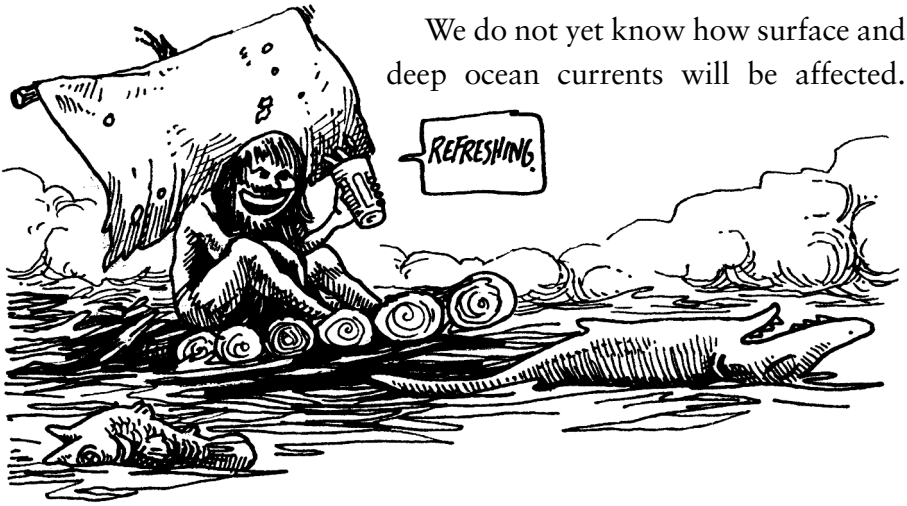
The global rise in sea level would affect many areas, including:

- The coastal United States, especially the states of Florida, Texas, North Carolina, and Louisiana
- The Netherlands
- Low-lying islands in the South Pacific and Indian Oceans (the Carteret Islands, and the Maldives)
- The Baltic shore of Poland, and
- The delta regions of Bangladesh.

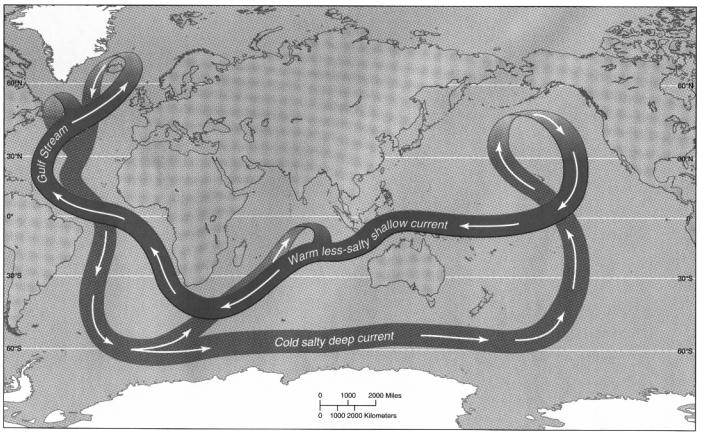
Changing Ocean Currents

Water has unique heat-absorbing properties, and as the oceans get warmer their currents could be affected. However, the IPCC suggest that there will be continuing warming of the ocean during the 21st century, and heat could transfer from the surface to the deep ocean and alter ocean circulation patterns. Vertical mixing occurs naturally between layers of warmer water that lie on top of the cooler layers at the bottom of the oceans. Ocean currents are connected, forming a conveyer belt system. Warm, lower salinity water on the surface circulates from the Pacific Ocean, through the Indian Ocean, and the North and South Atlantic before cooling, becoming more salty, and sinking to return back to the Indian and Pacific Oceans in cold deep currents. The influx of freshwater from the melting sea ice and glaciers will alter the salinity of the seawater and could affect this global circulation.

We do not yet know how surface and deep ocean currents will be affected.



Some oceanographers and climatologists think that the Gulf Stream, perhaps the most well-known of these currents, could slow down. If these surface currents change, we may see a resultant change in global climate.



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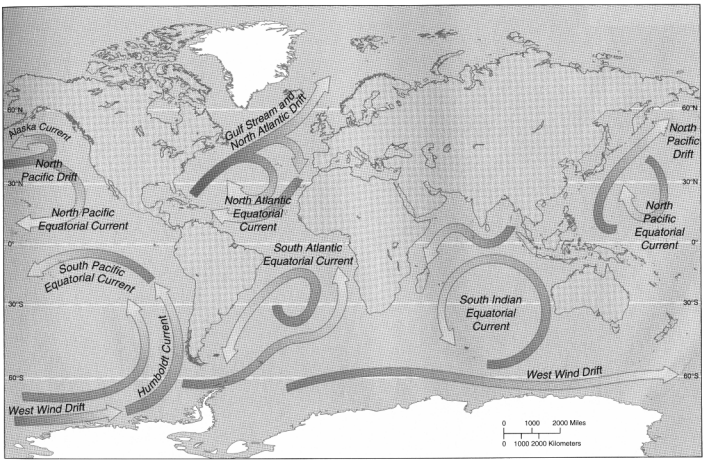

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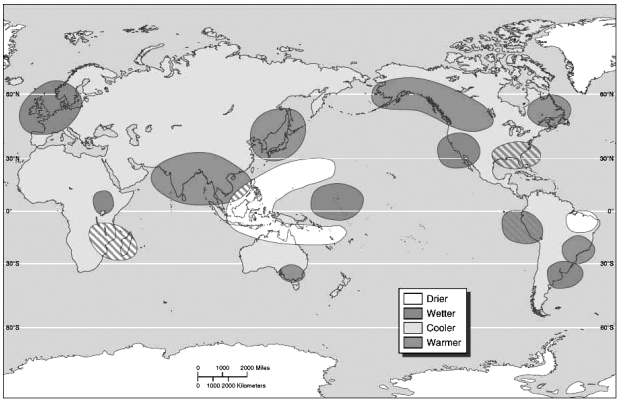
We may also witness a change in the El Niño event, which occurs periodically and lasts between nine to twelve months. During an El Niño year, warm ocean surface water moves from the western to the eastern Pacific Ocean. As a result, there is less rainfall in parts of Asia, Indonesia, and Australia, bringing drought to these regions, and an increase in rainfall and storms along the Pacific coast of North and South America, bringing flooding and mudslides. It is anticipated that as ocean temperatures change due to enhanced global warming, the frequency and the extent of El Niño events will increase. This in turn could result in climate changes on a global scale. Some regions will become drier while others will become wetter; some regions will become cooler while others become warmer.



Climate patterns related to an El Niño event

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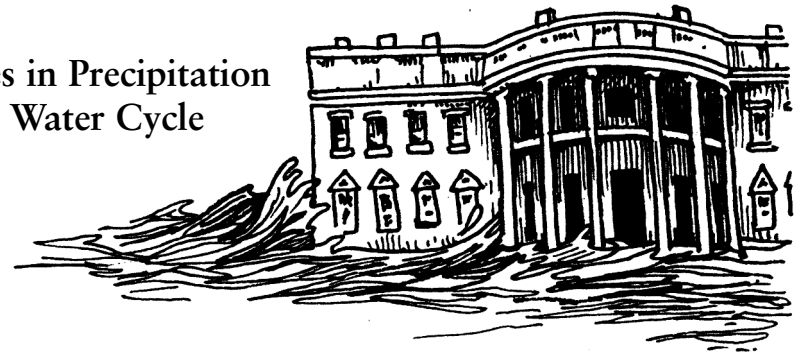
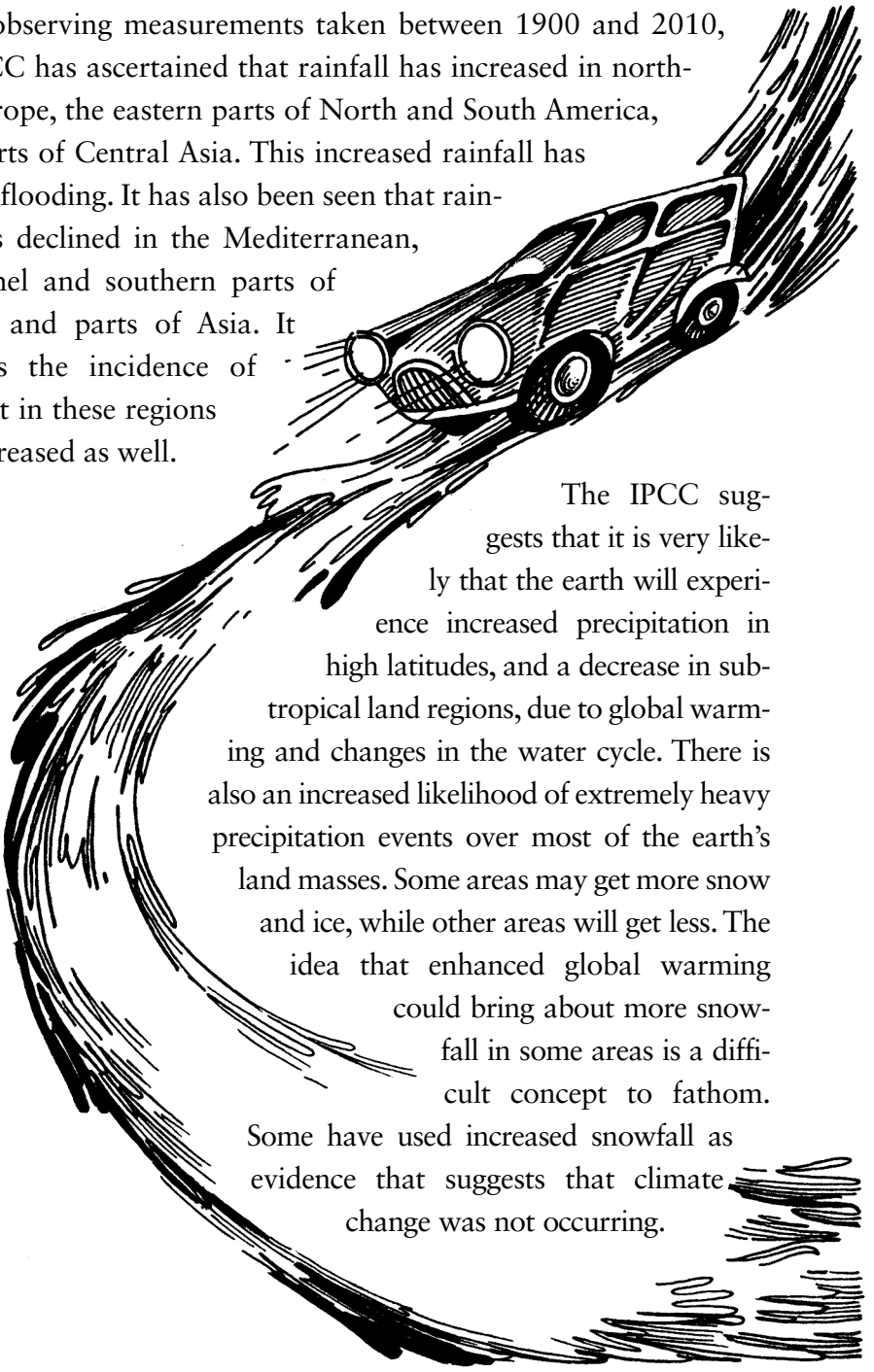
Changes in Precipitation and the Water Cycle



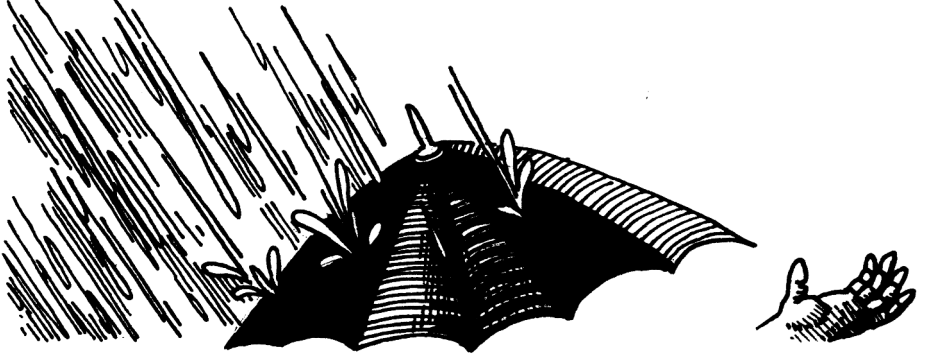
The water cycle is one of Earth's global systems. The changes in the water cycle over the 21st century will not be uniform; the contrast between wet and dry regions and wet and dry seasons will increase, and may be subject to regional exceptions. Powered by energy from the sun, water cycles through rainfall, surface water flow, sea currents, plant growth, and other processes all over the globe. The IPCC

has sounded the alarm for what is already being observed and what could occur in the future as enhanced global warming impacts this most fundamental of the earth's systems.

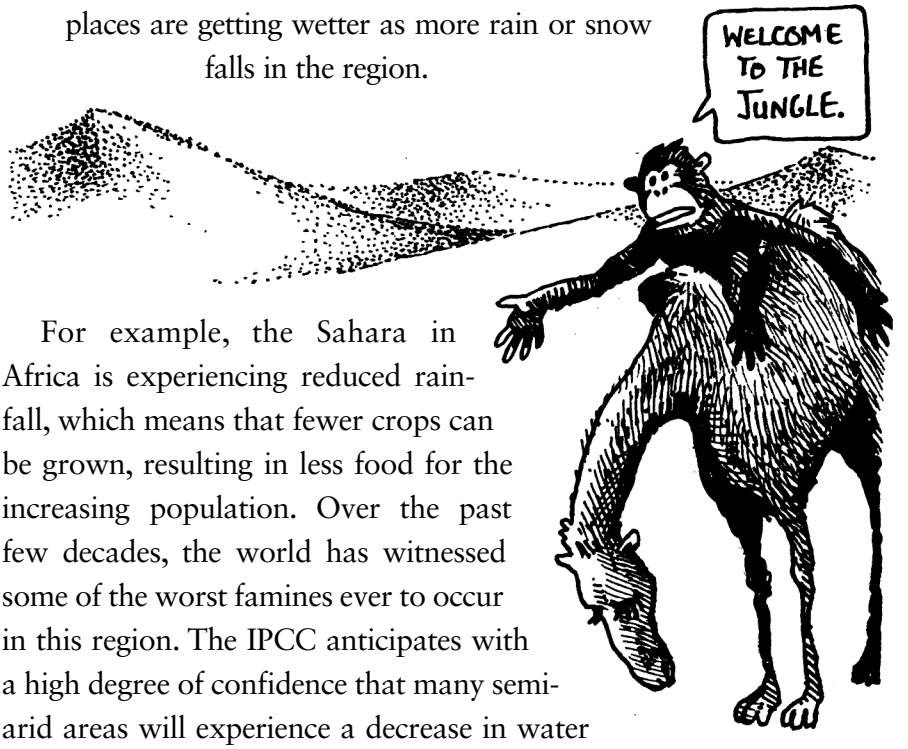
By observing measurements taken between 1900 and 2010, the IPCC has ascertained that rainfall has increased in northern Europe, the eastern parts of North and South America, and parts of Central Asia. This increased rainfall has caused flooding. It has also been seen that rainfall has declined in the Mediterranean, the Sahel and southern parts of Africa, and parts of Asia. It appears the incidence of drought in these regions has increased as well.



The IPCC suggests that it is very likely that the earth will experience increased precipitation in high latitudes, and a decrease in subtropical land regions, due to global warming and changes in the water cycle. There is also an increased likelihood of extremely heavy precipitation events over most of the earth's land masses. Some areas may get more snow and ice, while other areas will get less. The idea that enhanced global warming could bring about more snowfall in some areas is a difficult concept to fathom. Some have used increased snowfall as evidence that suggests that climate change was not occurring.



As the temperature of the oceans and land masses increase the heat they contain is radiated into the atmosphere, causing an increase in air temperature. Warmer air can hold greater amounts of water than cold air. Those of you that live in warm, moist climates will understand that idea—it's called *humidity*! In warm areas, more water can evaporate from the soil, or from surface water, and move into the atmosphere. The water vapor rises and forms clouds, which travel long distances through the action of the wind and relocate the water to another part of the earth. More water vapor means more clouds and more clouds means more precipitation—either rain or snow. So some places are getting drier as more water evaporates from the region, and some places are getting wetter as more rain or snow falls in the region.



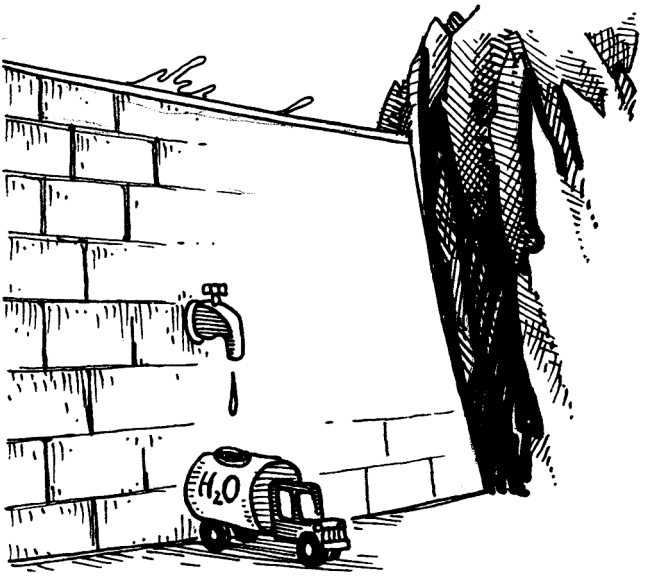
For example, the Sahara in Africa is experiencing reduced rainfall, which means that fewer crops can be grown, resulting in less food for the increasing population. Over the past few decades, the world has witnessed some of the worst famines ever to occur in this region. The IPCC anticipates with a high degree of confidence that many semi-arid areas will experience a decrease in water

resources due to climate change brought about by enhanced global warming. Desert regions will spread, due to less rainfall and more evaporation. Changes in precipitation patterns can only lead to increased conflict over water resources in areas of the world, such as the Middle East, that already have limited water supplies. Decreased rainfall and higher incidence of drought means more wars over water.

Many areas have experienced an increase in the frequency and intensity of flooding. Summer 2005 brought devastating floods to parts of Europe. Parts of Asia are witnessing increased flooding, and during July 2007, parts of England experienced some of the worst flooding in that country's history. Then between December 2013 and January 2014, the United Kingdom experienced the most exceptional period of rainfall in 248 years resulting in even more flooding! Every year heavy rainfall causing major floods continue to be an increasing problem throughout the contiguous United States.

This flooding and drought that is brought about by changes in the water cycle can also lead to some confusion. For example, how can an area like California be in one of the worst droughts in its history, then a few months later experience some of its worst floods? Why doesn't the rainwater ease the drought? Why does it instead cause mudslides and other problems? Many factors come into play. Because we have altered the land surface through activities such as housing developments and road construction, when it rains, a lot of the water runs off a hard surface, rather than infiltrating the soil and replenishing the groundwater. The water table drops as there is less input of groundwater; wells dry up or have to be dug deeper, and in some areas water conservation measures have to be enacted like banning the watering of lawns and washing cars. Then when it rains the water runs off into the gutters, roads, streams, and rivers, resulting in flooding. This is exacerbated if a lot of rain falls in a short period of time. Too much rain cannot be handled satisfactorily by a municipality's storm water drainage system. Sometimes water saturates the ground, causing it to become unstable and slide. The floodwater eventually flows back to the ocean through streams

and rivers as it travels on its way through the water cycle. So even during a period of drought we can have flooding, which does little to provide long-term relief from the drought!



In order for humans to have a constant water supply, we have had to look to other parts of the water cycle, tapping into the resources of rivers and lakes. Rivers have been diverted to provide water for human consumption and irrigation purposes. The effects of our actions can be seen in even the greatest rivers —the Indus, the Nile, the Colorado, and the Niger; and in bodies of water such as Asia's Aral and Caspian seas, lakes Chad and Malawi in Africa, and North America's Mono and Great Salt lakes. Although the changes that can be seen in these rivers, lakes, and seas can be mostly attributed to overdrawing and water diversion projects, we can only speculate the extent to which climate change will compound the problems in the future. As the water temperatures in rivers and lakes increase, water quality and the thermal structure of these aquatic ecosystems may be affected. Many temperate lakes and ponds are subject to a semiannual turnover each fall and spring—a vertical mixing of warm and cold layers—which is an important process in the life of a lake or pond. The effect that climate change may have is yet to be fully recognized.

The water cycle is in part responsible for the weather that we experience on a daily basis and the climate that we experience in our region over the longer term. Monsoons and tropical storms may become more intense. There has been an increase in tropical storm activity in the North Atlantic Ocean. We are also observing changes in wind intensity and wind patterns. As the oceans get warmer and radiate

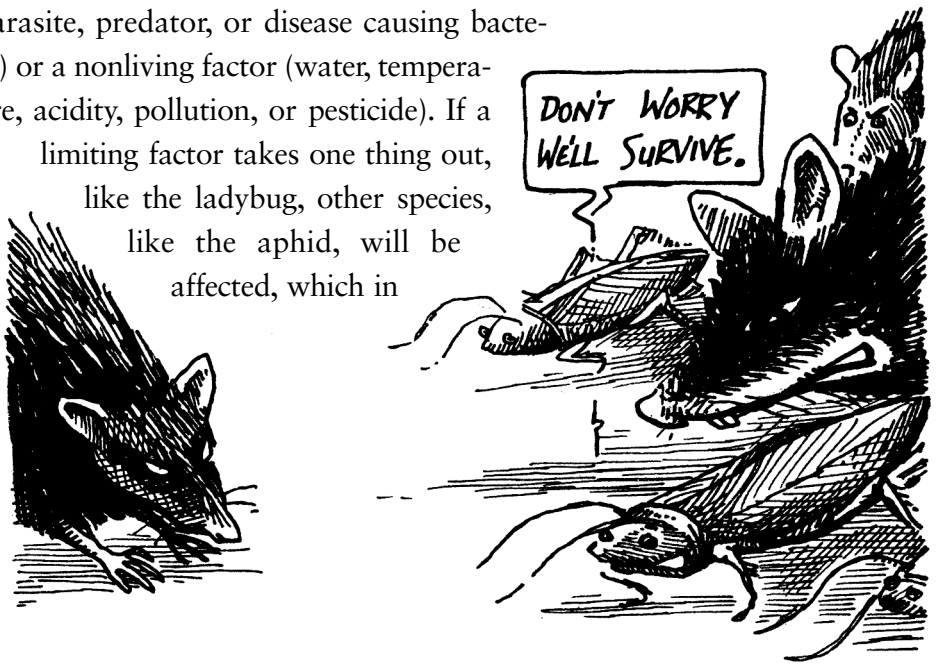
greater amounts of heat to the atmosphere, the strength and energy of ocean storms may increase. We are familiar with the names of the hurricanes that formed in the Atlantic Ocean recently—Andrew, Mitch, Ivan, Emily, and of course 2005's devastating Katrina, and 2012's Sandy. We may not be as familiar with the Pacific Ocean's typhoons—Amang in 2007 and Chanchu in 2006—or the cyclones of the Indian Ocean—Akash and Gonu in 2007. Currently, the IPCC cannot establish any clear link between global warming and increased storm frequency and intensity; it is a difficult systems analysis problem. Dr. Kerry Emanuel of the Massachusetts Institute of Technology has evaluated the data, and he believes that "hurricanes are lasting longer and getting stronger because of global warming." Other climatologists argue that there is insufficient data to conclusively make that claim. What is clear, however, is that increased global temperatures affect the water cycle causing changes in precipitation patterns worldwide, which could in turn affect the severity of some weather events. Indeed, two recent reports, one from the National Academy of Sciences, USA in 2013, and the other from the Met Office, UK in 2014, both linked the increased severity of thunderstorm and rainfall events directly to the consequence of climate change.

The Effect on Ecosystems and Biodiversity

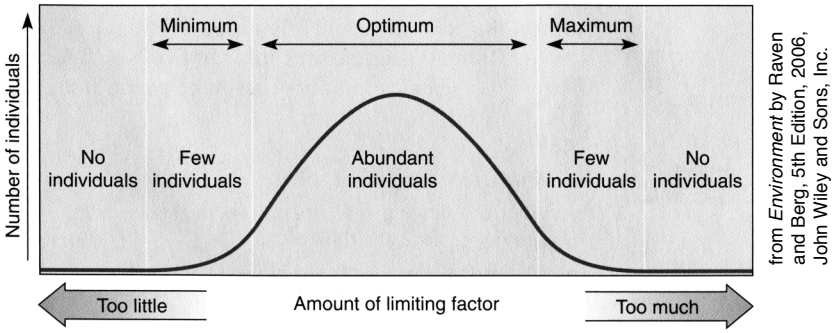
Just as our body's metabolism takes place within an optimal temperature range, so do many of the natural world's cycles and systems. When the temperature rises too high, or drops too low, there could be far-reaching consequences within an ecosystem. We are already observing some effects of climate change on species and ecosystems. Through our knowledge of how ecosystems operate, we can use logical, critical thinking to make predictions as to other consequences that may take place as climate change continues.

There are many things that a plant or animal species requires for its ongoing survival: heat, water, food, minerals, oxygen, carbon dioxide, acidic or basic conditions. If all of the parameters are at satisfactory levels then the organism thrives. However, if only one of the parameters falls above or below the optimal range, the species will be adversely affected. The parameter that is not at the optimal level, thereby limiting a species' population, is known as the *limiting factor*. For example, a shortage of water during a period of drought can cause a decrease in the number of both plants and animals in an ecosystem. This then has an effect on the biodiversity of that ecosystem.

Biodiversity refers to the numbers and types of all of the species in an area. If a limiting factor causes a decrease in the numbers of ladybugs, a predator for example, there could be an increase in the number of aphids (which eat plants and are eaten in turn by ladybugs), and increased damage to plants within that ecosystem. When an area begins to lose some of its biodiversity, the whole ecosystem suffers. The interdependence of all species within the ecosystem is controlled by a number of limiting factors which could act as a system input or output. The limiting factor could be a living organism (parasite, predator, or disease causing bacteria) or a nonliving factor (water, temperature, acidity, pollution, or pesticide). If a limiting factor takes one thing out, like the ladybug, other species, like the aphid, will be affected, which in

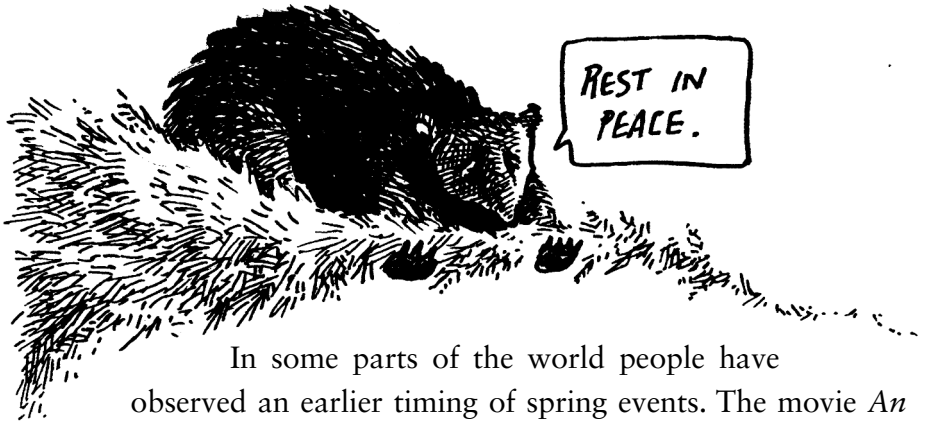


turn can have a knock-on effect on plants in other parts of the ecosystem. For example, the Asian ladybug has been introduced into North America (input) and it is competing with native species of ladybugs for food and habitat. This is causing a decline in the native ladybug populations (output). If you took one of the spark plugs from your car's engine, the car would not operate at its optimal level. Eventually other things may occur to the engine as a result and cause the car to break down completely. Increased global temperature can have similar detrimental consequences in many terrestrial and aquatic ecosystems.

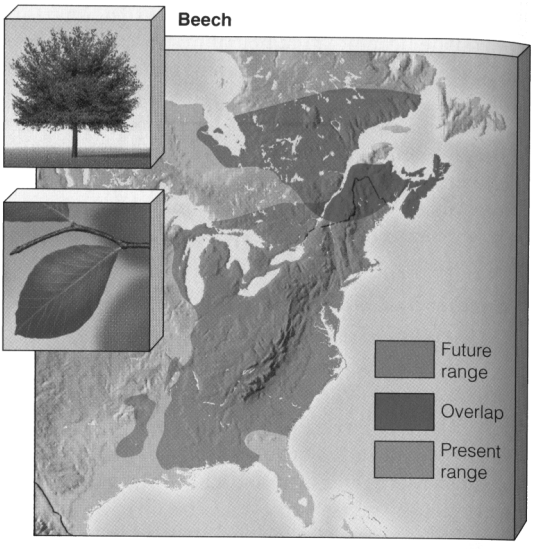


Too much or too little of any environmental resource can affect the number of species in a population

The IPCC has determined with a high degree of confidence that "20–30 percent of assessed species are likely to be at increased risk of extinction . . . and could be as high as 40–70 percent if global temperatures continue to rise." A report in the journal *Science* in May 2015 suggests that one in six of the world's species faces extinction due to climate change. The extinction of the golden toad in Costa Rica has previously been linked to climate change that aggravated a deadly disease. Some of the world's most vulnerable species include the Arctic ringed seal, the golden bowerbird of Queensland, Australia, the American pika, the Haleakalā silversword found only on the island of Maui, Britain's golden plover, and Namibia's long-lived quiver tree. In the past 40 years the world has lost around half of its animals due to pressures such as climate change, habitat loss, deforestation, pollution, and overfishing according to the World Wildlife Fund.



In some parts of the world people have observed an earlier timing of spring events. The movie *An Inconvenient Truth* examined the shifting seasons in the Netherlands, which has had an effect on some bird and caterpillar populations that are dependent on one another. In Great Britain some butterfly species have disappeared from some areas and are now found in areas that they previously did not inhabit. In the United States increased damage to trees by the pine bark beetle has been noted. In Yellowstone National Park, a decrease in trees due to increased beetle infestation as a result of the warmer climate may have an effect on the population of grizzly bears, which depends on the trees as part of its food source. Increased temperatures have been linked to the decrease of mangrove trees in parts of the Florida Everglades.



from *Living in the Environment* by Miller, 15th Edition, 2007, Thomson Higher Education.

Other concerns that have been raised regarding the effect of climate change on ecosystems and biodiversity include:

- Swamp, marsh, and wetland habitats may become drier in some areas.
- Drier soils may result in increased incidence of wildfires in some forest and woodland areas.

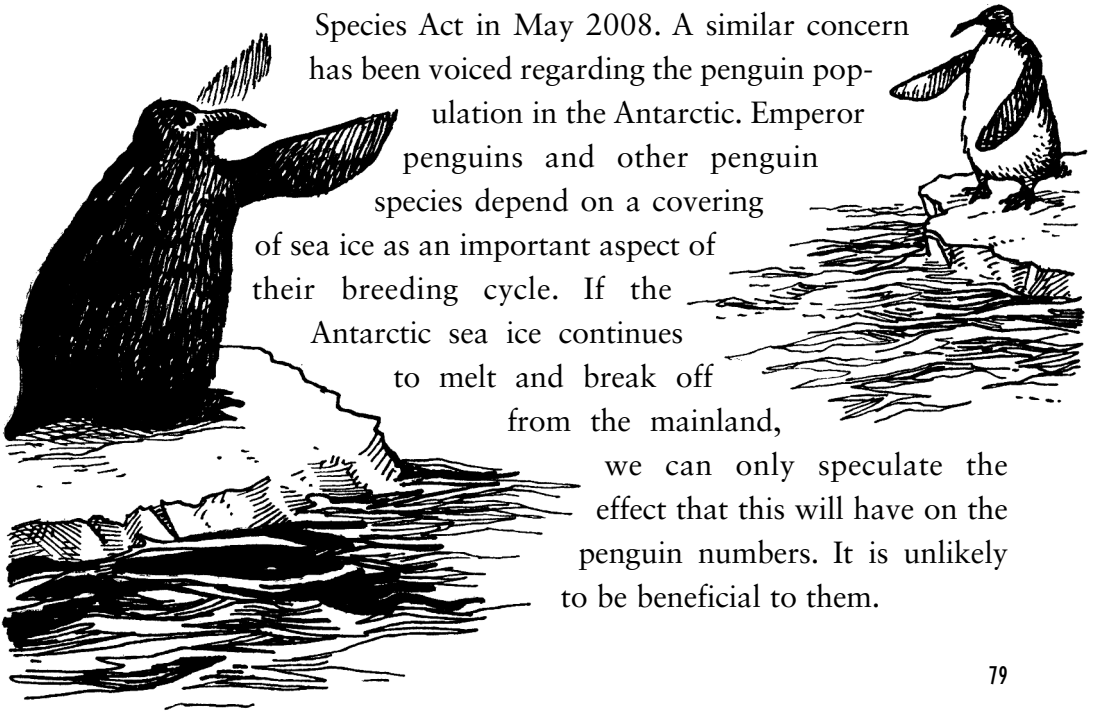
- Agricultural crop production could be reduced as a result of heat stress on plants, water shortages, and increased plant diseases.

- Some poisonous plants, such as poison ivy, may become more toxic.

- The ranges of some plant and animal species may change. For example, researchers at the University of Minnesota have suggested that beech trees, which are common throughout eastern North America, may in the future only be found in the northern part of Maine and the southeastern region of Canada.

The full extent of any or all of these consequences on terrestrial ecosystems remains to be seen; much depends on how quickly and effectively the human race responds to the challenges of climate change by reducing greenhouse gas emissions.

There is already concern about the effect decreasing Arctic ice coverage will have on the population of polar bears that use the ice packs for travel and hunting. Obviously if the ice sheets decline or disappear altogether then this must have a detrimental effect on any species that use them as an important part to their existence. As a result of the continuing loss of their sea ice habitat due to climate change, polar bears were listed as a threatened species in the US under the Endangered Species Act in May 2008. A similar concern has been voiced regarding the penguin population in the Antarctic. Emperor penguins and other penguin species depend on a covering of sea ice as an important aspect of their breeding cycle. If the Antarctic sea ice continues to melt and break off from the mainland, we can only speculate the effect that this will have on the penguin numbers. It is unlikely to be beneficial to them.



Rising water temperatures in marine and freshwater ecosystems have also resulted in changes in their natural balance and biodiversity. In addition to changes in ice cover, there have also been alterations in salinity, and of dissolved oxygen and carbon dioxide levels. Concern has been raised regarding the future productivity of the world's fisheries, which are already threatened by overfishing. Declining populations of a number of algae and plankton species have been noted. An algal bloom can result in dead zones in aquatic ecosystems, as was observed in the Baltic Sea in 2005. As algae dies and drifts to the bottom of a body of water, it provides food for decomposers. As the decomposers feed on the dead algae they consume oxygen and release carbon dioxide through the process of cell respiration. The water's oxygen level can fall so low that it is not sufficient to support aerobic life—think fish—and the area essentially becomes a dead zone. In addition to changes in water temperature, algal blooms can be triggered by increased inputs of nitrate and phosphate nutrients contained in runoff from agricultural regions. Phosphorus is often a limiting factor in algae growth; if there is phosphorus in abundance, there is abundant algae too. The aquatic ecosystems of the Chesapeake Bay, the largest estuary in North America, have been detrimentally affected by dead zones caused by algal blooms.

Algae also grow on the underside of sea ice and are an important food source for some marine species. A decrease in the amount of sea

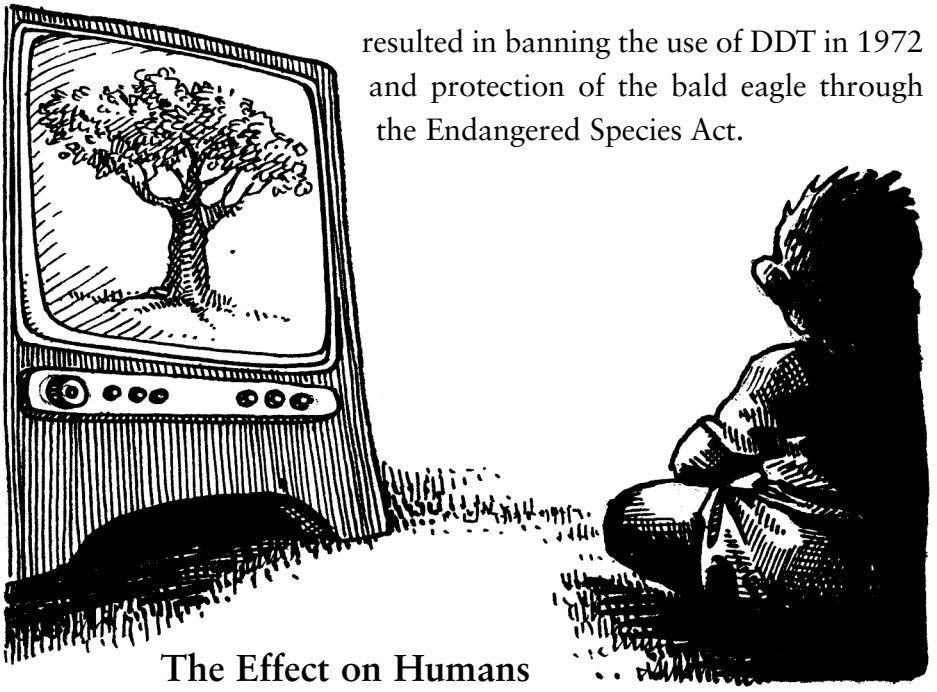
ice also means less algae and therefore less food for those species that depend upon them. It is likely that we will observe a domino effect throughout the whole marine food chain in some areas. There are already alarmingly decreasing krill populations in the Antarctic Ocean. This may be the result of human activities. If the Antarctic sea ice continues to melt as the water temperature increases then this will have a dramatic affect on the base of the Antarctic food chain. Less algae will be produced, which means less food for the krill, which means less krill, which means less food for the other marine species that depend on the krill, such as the blue whale. Again, it is evident that a disruption to one part of the system can have widespread consequences.

Many of the world's most pristine coral reefs have been under threat for a long time as a result of pollution and other human activities. Increasing ocean temperatures may only compound the problem. Coral reefs are often referred to as the "rainforests of the ocean" and their high biological productivity is of great importance to many species of marine life. Coral consists of an animal, the coral polyp, and a plant, zooxanthellae, living in close harmony with each other in a mutually beneficial relationship. The coral polyp provides the zooxanthellae with a protected place to live, and the zooxanthellae provides the polyp with food produced by photosynthesis. (That's why coral reefs are only found in the upper surface of the ocean in the region where light can penetrate, called the *euphotic zone*.) Coral provides an example of an important, finely-tuned interaction between two different species within the marine ecosystem. Both species need each other for survival. *Coral bleaching* occurs when the beautifully colored coral becomes a ghostly white—the coral has died. If the water temperature gets too warm and becomes out of the range of tolerance for the zooxanthellae they are expelled from the coral. The orange-spotted filefish is now locally extinct around Japan due to coral bleaching. Enhanced global warming that gives rise to warmer ocean temperatures is just another human-induced detriment to affect the coral reefs and the other marine species that are dependent upon them for their continued existence.

Effects on Ocean Chemistry

An idea to emerge over the past few years is the concern that the acidity of the seas and oceans could increase due to the higher levels of dissolved carbon dioxide that occur in warmer waters. This hypothesis is being investigated through ongoing scientific studies; it is a rational expectation based on current knowledge. We know that when carbon dioxide dissolves in water it forms carbonic acid, so we could draw a conclusion that more dissolved carbon dioxide leads to more carbonic acid which could then react with and affect the shells of marine species. The increased acidity could affect the calcium metabolism of shell-forming marine life. It may also impact the skeletal formation of bony fishes. NOAA has found that "Since the Industrial Revolution, the global average pH of the surface ocean has decreased by 0.11, which corresponds to approximately a 30% increase in the hydrogen ion concentration. This ocean acidification, related to the uptake of carbon dioxide at the ocean surface, causes a relatively slow, long-term increase in the acidity of the ocean, corresponding to a decrease in pH. So why are scientists concerned about such a seemingly small change in pH? Many organisms are very sensitive to seemingly small changes in pH. For example, in humans, arterial blood pH normally falls within the range 7.35–7.45. A drop of 0.1 pH units in human blood pH can result in rather profound health consequences, including seizures, heart arrhythmia, or even coma (a process called acidosis). Similarly, many marine organisms are very sensitive to either direct or indirect effects of the change in acidity (or H+ concentration) in the marine environment. Fundamental physiological processes such as respiration, calcification (shell/skeleton building), photosynthesis, and reproduction have been shown to respond to the magnitude of changes in carbon dioxide concentrations in seawater, along with the resultant changes in pH and carbonate ion concentrations that are expected over the next century. It is interesting to note that in the 1960s DDT was found to affect the calcium metabolism and therefore eggshell formation in birds like the bald eagle and the osprey. This finding

resulted in banning the use of DDT in 1972 and protection of the bald eagle through the Endangered Species Act.



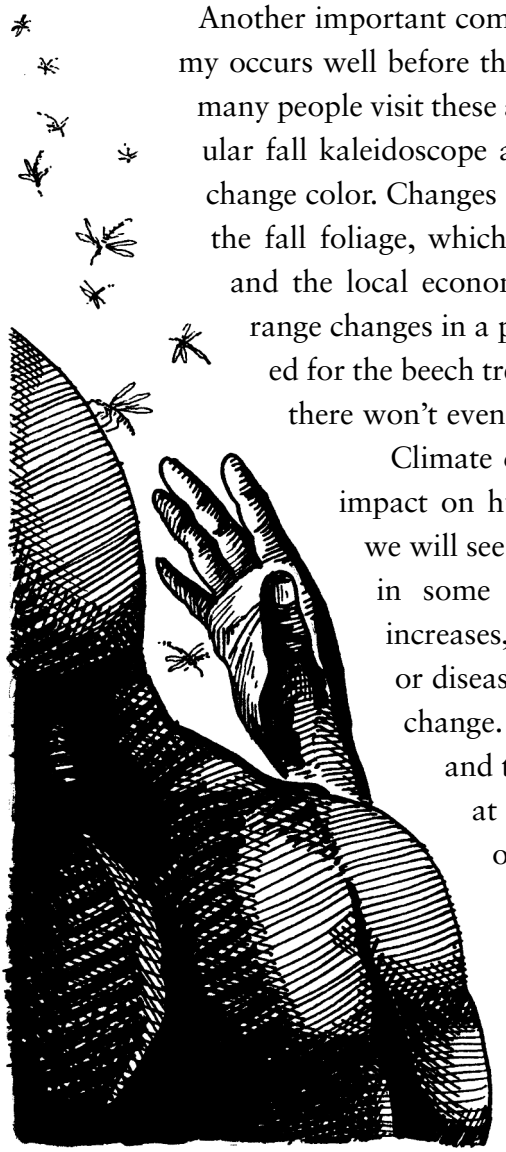
The Effect on Humans

Humans rely on the natural capital provided by the earth for many activities at all times of the year. In recent generations we seem to have become disconnected with the natural world and have withdrawn from nature, not fully appreciating its wonder as we once did. This argument is eloquently expressed in Richard Louv's *Last Child in the Woods*. Even so, many people still go out into the natural world and participate in many activities—hunting, skiing, snowboarding, bird-watching, snowmobiling, snow shoeing, horseback riding, photography, hiking, leaf-peeping, camping, ice fishing, fishing . . . the list goes on! What could climate change do to limit the recreational activities that we love to participate in?

Not only could global warming have an effect on the aesthetic pleasure we receive from nature, but in many instances it could have economic consequences as well. For example, if a region that relies on skiing as part of its winter tourism activity receives less winter snow and more winter rainfall, then people will not come to the area to ski. The whole economy—from ski resorts to hotels and restaurants—will not have a good year financially. Businesses could close

after a few years of low snowfall, particularly if the trend becomes a permanent feature and consequence of enhanced global warming's effect on climate. Ski seasons could become shorter, and in fact all mountain sports could be affected.

The northeastern United States and Canada have a thriving maple syrup industry that is dependent upon cold winters for the sap to run well in the spring thaw. Warm winters are already impacting the amount of maple syrup that has been produced in recent years.



Another important component of the region's economy occurs well before the sap starts to run. In the fall many people visit these areas to marvel at the spectacular fall kaleidoscope as the maples and other trees change color. Changes in regional climate may affect the fall foliage, which in turn will impact tourism and the local economies. And if the maple trees' range changes in a pattern similar to that predicted for the beech tree (see page 78) in many areas there won't even be a maple to see!

Climate change has begun to have an impact on human health. It is likely that we will see changes in infectious diseases in some places. As the temperature increases, the range of disease-carrying or disease-causing insect vectors could change. For example, the mosquito and tsetse fly are now found living at higher altitudes in some parts of Africa. A warming globe could bring about the spread of diseases such as malaria that prior to the temperature changes were not a problem in certain regions. This is of particular concern

if you happen to be a resident of Harare, Zimbabwe, or Nairobi, Kenya, as these two cities are at elevations that mosquitoes previously did not inhabit. Now these cities are at risk due to the migration of mosquitoes to the higher altitudes as the temperature warms. Time will tell how widespread the changes in infectious diseases will become. Higher carbon dioxide levels have been implicated in increased amounts of ragweed pollen. This could lead to detrimental effects for those who are susceptible to allergies and prone to respiratory distress caused by asthma.

The entire human population is vulnerable to the threats posed by climate change brought about by global warming, because everyone is susceptible to the effects of drought, flood, heat wave, disease, and famine. No one is immune from the risks posed by climate change.

Will Global Cooling Help Offset the Consequences of Enhanced Global Warming and Climate Change?

We know that substances in the atmosphere, such as dust, smoke, soot, and aerosols can reflect sunlight back into space and as a result cool the planet. This phenomenon was apparent in the aftermath of the eruption of Mount Pinatubo in 1991. James Hansen, a former NASA scientist, put together a climate model that suggested the earth would initially cool due to the smoke and ash discharged into the atmosphere from the volcanic explosion. After a period of time he predicted that the earth would then warm up and return to its pre-eruption temperature. His climate model was found to be correct as global temperatures were monitored over the succeeding years.

Some particles can also absorb sunlight and radiate heat toward the earth's surface. There are also natural processes that occur in the atmosphere that clean the air of pollutants through chemical reactions. Some of the positive and negative feedback mechanisms that operate in the atmosphere are complex and cause scientists to argue as to the extent that any global cooling effect may have. For example, sulfates reflect solar energy back into space (negative feedback) whereas black carbon (soot) particles absorb energy (positive feed-

back). Aerosols can also result in cloud formation and make clouds more reflective.

Professor Richard Lindzen, an atmospheric scientist at the Massachusetts Institute of Technology, believes that aerosols in the atmosphere will actually make the earth cooler in 20 years than it is today, and that global warming as a result of human-induced effects is exaggerated.

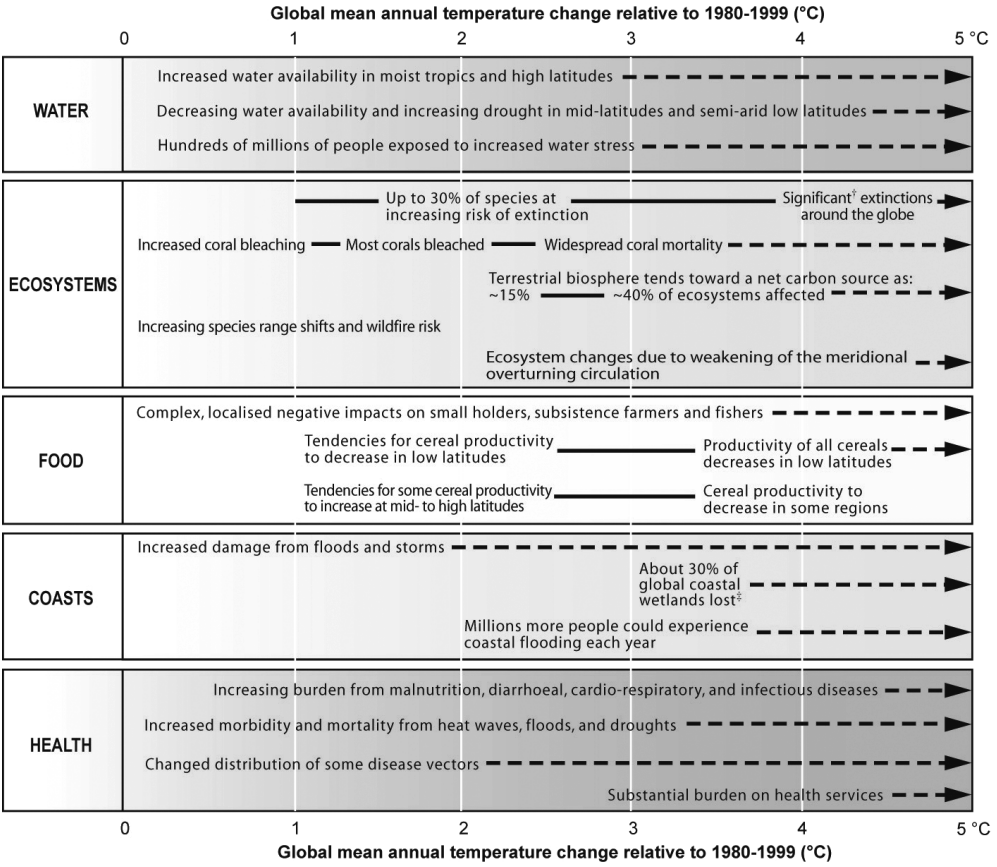
Professor Alan Thorpe, a renowned meteorologist and head of the Natural Environmental Research Council believes otherwise. "Although there are significant uncertainties in certain aspects of the [system] models, particularly in the effects of clouds, there was no reason to suppose that the models have a systematic bias towards human-induced global warming. If anything the models have underestimated the degree of warming," he suggests. The complex positive and negative feedbacks from aerosols were not included in the older climate models but are included in the climate models used today.

More research is warranted in the area of global cooling and its potential impact on global warming. In fact, the enhanced global warming that traps heat in the troposphere causes the stratosphere to get colder, which results in an increased breakdown of the ozone layer by CFCs! Such is the interconnection of the atmospheric systems. Any cooling effect of the pollutant particles is only temporary due to their short residence time in the atmosphere. Their concentrations also vary globally by region, and as air pollution is overall being reduced, it is highly unlikely that their cooling effects will counteract any projected atmospheric warming trends in the future. It has recently been shown that contrails from jet aircraft can also have a cooling effect on global atmospheric temperatures. So how much will contrails effect global temperature? James Hansen, currently a professor at the Earth Institute at Columbia University in New York, used climate models and found only a small amount of temperature change, possibly around 0.03°C (0.05°F) from the contrails. Hansen told Peter Tyson, a reporter for the 2006 NOVA program *Dimming the Sun*, "Aircraft are likely to be a significant factor

in future climate change, but probably not via their contrails. I think our main concern about aircraft will be their carbon dioxide emissions."

One thing is certain; the overall trend is that the earth is warming despite any impact that global cooling is having on the system as a whole. It is probably not a good idea to pollute the atmosphere with more dust, smoke, or soot in the hope that these particles will help cool down the earth! Nor would it be logical to increase sulfate particles (that lead to acid rain) just because they may have a cooling effect in the atmosphere. There are other, more sustainable ways to reduce the extent of enhanced global warming and its impact on climate change in the future.

The IPCC has summarized the examples of impacts associated with global average temperature change in the table below.



† Significant is defined here as more than 40%.
‡ Based on average rate of sea level rise of 4.2 mm/year from 2000 to 2080.