Bracing for Climate Change in the Constitution State




WHAT CONNECTICUT COULD FACE

ENVIRONMENTAL DEFENSE
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Environmental Defense is dedicated to protecting the environmental rights of all people, including the right to clean air, clean water, healthy food and flourishing ecosystems. Guided by science, we work to create practical solutions that win lasting political, economic and social support because they are nonpartisan, cost-effective and fair.

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Executive summary

Scientists from around the world agree that climate change is real and that the main cause of rising temperatures over the past century has been human activity. Connecticut's environment, public health and economy are likely to suffer significant adverse effects from climate change. This summary describes the findings of an in-depth report on the impacts of climate change on Connecticut, in which we present data that shows Connecticut is growing warmer. We use climate models to project future accelerated temperature rise, sea-level change, and outline the impacts to health, ecosystems and the economy. Climate change presents a serious challenge for Connecticut, but forward-thinking policies and existing technology can significantly reduce our greenhouse gas emissions and prevent risking the health and safety of our people and our environment.

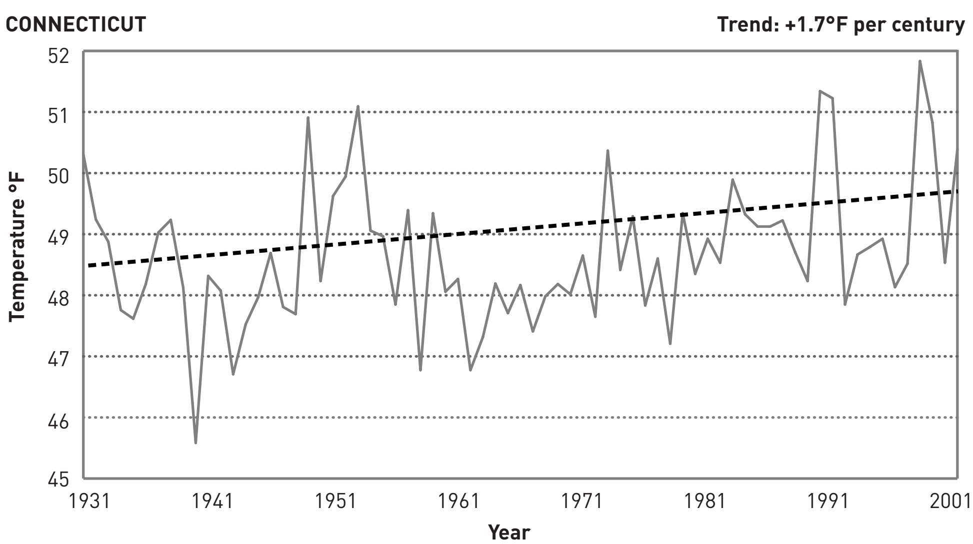
Temperature trends in Connecticut

A region's temperature is one of the defining traits of its climate. Even small shifts in average temperature can result in drastic changes in a region's climate system. These changes, especially when rapid, can have devastating effects on ecosystems and their inhabitants. Over the past century, the temperature in Connecticut has been gradually warming. The mean annual temperature for the entire state is increasing at a rate of 1.7°F every 100 years (see Figure ES-1). In certain areas, particularly along the southern shore, the rate of warming is nearly doubled, increasing 3.5°F per 100 years. The temperature increase in Connecticut is greater than the increase in the rest of New England.

Although temperature projections are not resolved to a scale as small as an individual state, we can use models to get a general sense of future climate.

FIGURE ES-1

Connecticut has slowly warmed over the last century



Source: Data from NCDC: www.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html.

Will global warming put an end to the region's lobsters?

Lobsters have been a part of Jim King's life for more than 50 years. Jim's father was a fisherman in the Long Island Sound off New York and Connecticut, and Jim has been a lobsterman himself for more than 40 years. He has a real appreciation for the mysteries and charms of lobsters: "Every time you think you know something about them, they do something unexpected. They're very unique animals," he says.

Jim King

Jim has seen good and bad years since he started trapping lobsters almost half a century ago. But in 1999, lobsters in the area began dying in record numbers. In some parts of the Sound, nearly all of the lobsters died. Jim remembers the horror stories: Fellow lobstermen pulled up traps filled with dead animals. By 2003, lobster populations were down 70% from 1998 levels.[1] It was more than just a bad year.

Although many factors, such as pesticide runoff, likely played a role, most scientists concur that warmer water temperature was one of the leading causes of the lobster die-off. A lobster's body temperature is determined by the temperature of the water it lives in, and laboratory studies show that water temperatures above 75–85°F are lethal to lobsters. The record-breaking heat during the summer of 1999 and 2002 most likely resulted in warmer water temperatures that contributed to the mass deaths.

The economic impacts of the lobster die-off have been devastating. The value of the Long Island Sound lobster fishery fell from $42 million in 1998 to $10 million in 2002. Though Jim has been able to survive the hard times, many lobstermen in Long Island Sound have been plunged into financial ruin.

It will take at least several years for the lobster population to rebound. But their long-term survival remains in question. If current rates of global warming continue unchecked, it is possible that water temperatures in the Long Island Sound will become so warm that lobsters will no longer be able to survive there.

Limiting emissions of the greenhouse gases that cause global warming could help keep water temperatures at a suitable level for lobsters to thrive. In addition, limiting polluted runoff and toxic pesticides will help ensure that lobstermen like Jim King can carry on the tradition of lobster fishing in the Long Island Sound for generations to come.

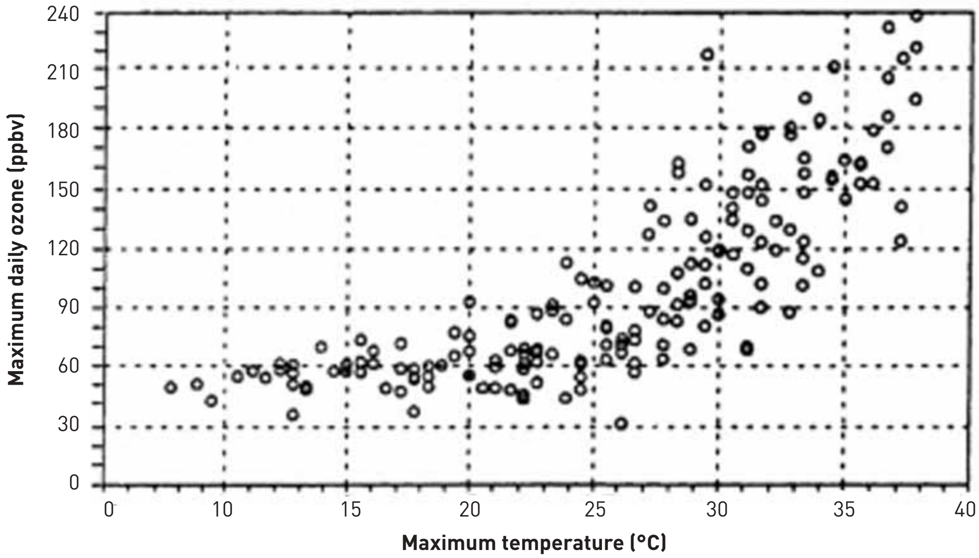
Analysis from the New England Regional Assessment projected temperatures to rise 2.5°F by 2030 and 4-9° by 2100. A 4° increase would make Hartford's climate similar to Philadelphia's. A 9° increase would make Hartford seem more like Raleigh.

Air pollution and human health

Connecticut has made significant strides in improving air quality, but high concentrations of ground-level ozone, or smog, still threaten the health of residents. In 2001, Connecticut ranked third in the nation, trailing only California and Texas, for the highest "peak" concentrations of ozone (when smog is at its worst on hot summer days). With the most unhealthy air in the New England region, the state was deemed by the EPA to be in violation of federal air quality standards.

FIGURE ES-2

As temperatures rise, so do maximum ozone levels in New York City



Source: USEPA. 1991. Aerometric Information Retrieval System (AIRS). Research Triangle Park, NC.

Rising temperatures caused by climate change will likely worsen the state's smog problem, especially in urban areas.

Temperature and ozone data from the New York-New Jersey–Connecticut metropolitan region, as well as climate models and simulated smog chamber studies, show a strong correlation between maximum daily temperature and peak ozone concentrations in the higher temperature ranges. In this region, a uniform increase in temperature of 7˚F would result in an almost 20% increase in ozone smog concentrations.

Especially troubling is the link between ozone and asthma. Ozone exacerbates asthma symptoms and triggers attacks. Connecticut's asthma rate surpasses the United States average, with more than 200,000 adults and 75,000 children affected across the state. In 1998, the treatment of asthma cost the residents of Connecticut approximately $134 million, a figure that is likely to increase as rising temperatures and smog levels increase the impacts of asthma.

TABLE ES-1

Asthma takes a toll on Connecticut counties

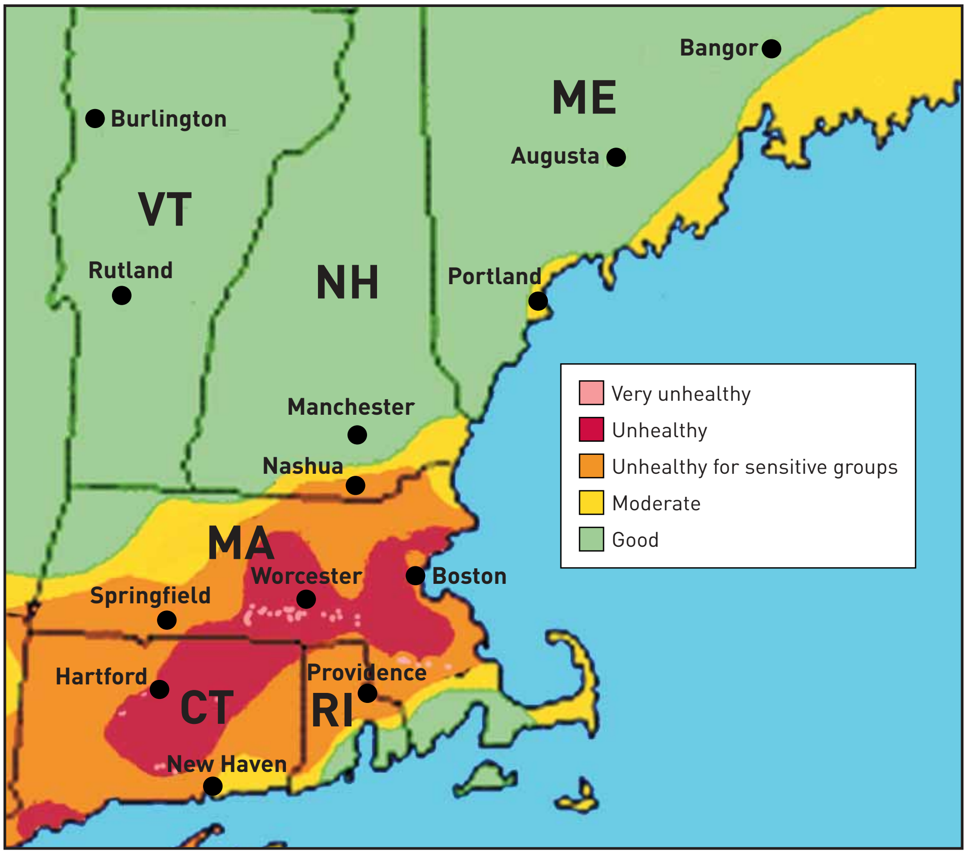
CT county	Adults with asthma	Children with asthma	Total costs
Fairfield	52,302	12,510	$33,935,000
Hartford	51,192	11,659	$34,388,000
New Haven	49,434	11,153	$32,637,000
New London	15,677	3,497	$10,138,000
Litchfield	10,844	2,480	$7,198,000
Middlesex	9,480	1,990	$5,943,000
Tolland	8,540	1,743	$5,368,000

Source: Asthma and Allergy Foundation of America. 1998. The Costs of Asthma in Connecticut. www.aafa.org/states/display.cfm?State=ct.

FIGURE ES-3

Connecticut leads New England in unhealthy air

Daily ozone level August 24, 1999



Source: USEPA. 1999. The Ozone Problem. www.epa.gov/region01/eco/dailyozone/oz_prob.html..

Heat-related illnesses and deaths

More than 14,000 people died as a result of the heat wave that hit Europe this summer. The World Meteorological Organization recently reported that as global temperatures continue to rise due to climate change, the number and intensity of extreme events such as heat waves will increase. In 2000, the United States experienced about twice as many high-heat-stress days (those with temperatures over 90°F) on average than in 1948. In Connecticut, models project that by the 2050s there will be on average almost 10 more high-heat-stress days per year than there were in the 1990s.

Periods of extreme heat cause most harm to regions unaccustomed to warm weather and unable to adapt to such conditions. Models indicate that northeastern U.S. cities are likely to experience the greatest number of heat-related illnesses and deaths from higher summer temperatures. Elderly populations and low-income groups are most vulnerable to heat stress. Living in urban centers increases the risk for these communities, which have limited access to air conditioning, adequate medical care and other resources.

Vector-borne diseases

Studies have shown that vector-borne diseases, or those transmitted by insects, may be temperature-dependent, increasing with warming weather. An increase in average global temperatures of several degrees by the year 2100 could increase by 100 times the capacity of insects to transmit disease in temperate regions like Connecticut. Most vector-borne diseases are seasonal, occurring during the warmer months when insect populations thrive and humans spend more time outdoors. Higher temperatures increase the opportunity for transmission of such diseases as Lyme disease and Eastern equine encephalitis. Higher temperatures also may allow insects and the diseases they carry to spread to new areas. Diseases formerly associated with warmer areas, such as West Nile Virus, dengue and malaria, may appear in temperate areas like Connecticut.

Sea-level rise

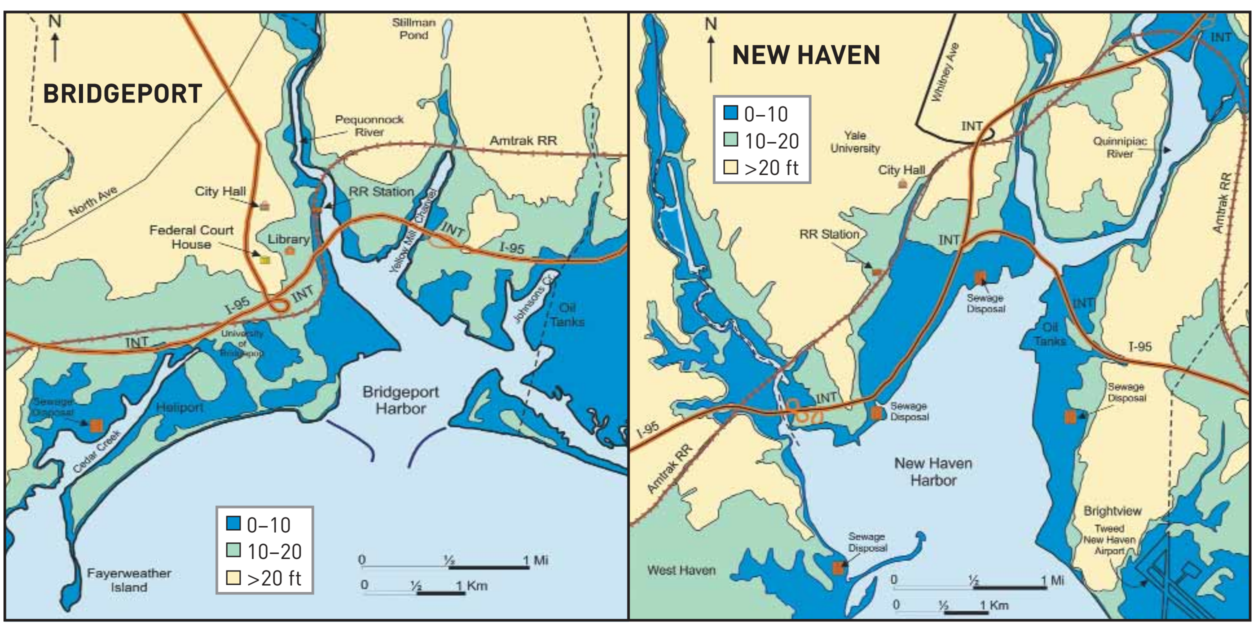
Rising sea levels caused by global warming would increase the threat to already at-risk coastal populations in Connecticut. Models project that by the end of this century, the rate of global sea level rise could increase by two to five times. This could lead to the inundation of low-lying coastal regions and more frequent and extensive flooding due to storm surges. The rise in sea level is likely to have negative impacts on coastal communities and coastal wetlands.

Connecticut's current rate of sea level rise is 0.10 inch per year in Bridgeport and 0.08 inches per year in New London. The rate exceeds the global mean trend of sea level rise, and the increasing rate projected for the next century will result in significantly higher sea levels for coastal Connecticut. Models predict a sea level increase of 5.1 to 8.3 inches by 2020, 8.1 to 16.7 inches by 2050, and 11.2 to 35.3 inches by 2080.

Storm surges from hurricanes and other storms are projected to increase in height as a result of sea-level rise. By the end of the century, a Category 1 hurricane

FIGURE ES-4

Areas potentially at risk to coastal flooding by hurricanes



By the 2080s, projected flood levels for Connecticut coastal cities during Category 3 hurricanes could range between 14.5 and 18 feet.

could produce storm surges similar to what we experience now with a Category 3 hurricane. Since Category 1 storms are more likely to occur than Category 3 storms, we can anticipate more frequent severe flooding. This increased flooding will affect several major Connecticut cities that have important infrastructure within the flood-hazard zone. In New Haven, this includes the railroad station and track yards, the Tweed-New Haven Airport and parts of the Connecticut Turnpike (I-95). In Bridgeport, vulnerable structures include portions of the Amtrak railroad, entrances to Connecticut Turnpike interchanges and bridges, the University of Bridgeport, the Navy Reserve Center, the Heliport, sewage disposal plants and the oil tanks at Johnson Creek.

Future sea-level rise could result in the disappearance of a large percentage of Connecticut's coastal wetlands, which are already stressed by development and other human activities. Wetlands are important because they serve as nurseries for fish and other animals, shelter migrating birds and help to filter pollution from drinking water. Using a simple model to assess the impact of sea-level rise on Connecticut's wetlands, we found that only wetlands with high accretion rates (or fast accumulation of sediments) could survive through mid-century, and even they would be completely submerged by 2080.

Strategies to adapt to rising sea levels could include structures such as seawalls and jetties. As a last resort, retreat from the shore may become an appropriate option, especially in areas of lower population densities, or in high-risk areas subject to repeated storm damage.

A number of federal, state and local government agencies are involved in flood management and relief. While current plans are more or less adequate to cope with disasters based on historic experience, little thought has been given to preparing for sea-level rise due to climate change. Sea-level rise is likely to be relatively small in the next 20 years, with a more rapid rise occurring in the second half of this century, so the next two decades should be spent developing mitigation and adaptation strategies.

Conclusion

Scientific consensus affirms that burning fossil fuels in cars and power plants has increased atmospheric concentrations of greenhouse gases. The gases act as a blanket, warming Earth and leading to higher temperatures and rising sea levels. The changes in climate will significantly impact Connecticut's health and economy. Fortunately, we can take actions now that will limit these impacts and help protect our homes and families. We in Connecticut have a responsibility to act because our contribution to climate change is significant: Connecticut emits more of the greenhouse gas carbon dioxide through the burning of fossil fuels than Venezuela and Chile combined. An obvious place to start reducing greenhouse gases is the transportation sector, which contributes 39% of Connecticut's total greenhouse gas emissions, the largest source in the state. By shifting to less-polluting fuels and more efficient vehicles, Connecticut will cut greenhouse gas emissions, reduce its dependence on oil and improve the state's air quality.

Introduction

From snowstorms to heat waves, weather affects the life of every Connecticut resident. But many don't realize their lives also affect the weather and the climate. Scientists from around the world agree that human activity is most likely the cause of the recent changes in the world's climate. Burning fossil fuels to power factories and cars and generate electricity releases greenhouse gases into the atmosphere. These gases, such as carbon dioxide and methane, act like a blanket that traps heat, warming the Earth. The higher temperatures are leading to significant changes in the Earth's climate that will affect every aspect of life.

Climate and weather

Weather, which we hear about on the news every day, refers to the daily fluctuations in an area's temperature, precipitation and wind patterns. Weather also refers to storms and other extreme weather events. Climate, on the other hand, is defined as the long-term average of the weather patterns for a particular area. Some examples of changes in climate include earlier summers or later winters, changes in total snowfall over the course of a winter and increased frequency of extreme weather events such as hurricanes. While weather can change drastically from day to day, the climate of an area generally changes on a much longer timescale, on the order of centuries and millennia.

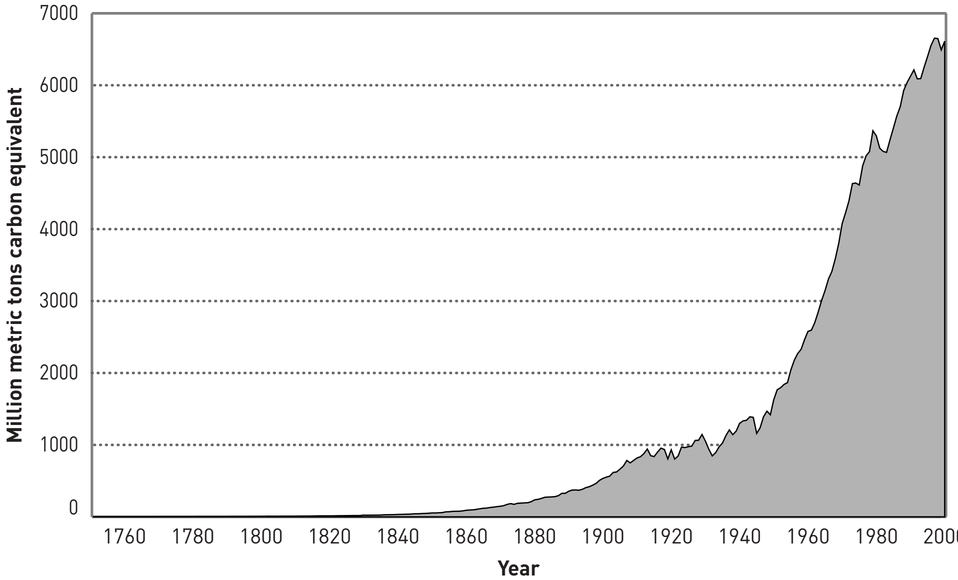
The greenhouse-gas effect

One mechanism that determines the Earth's climate is the greenhouse-gas effect. Every day, the Earth absorbs energy from the sun. This energy is then re-radiated out into space in the form of heat. As the heat passes through our atmosphere, greenhouse gases capture some of the heat and re-radiate it downward, causing the Earth's surface to warm. This blanket of heat-trapping gases allows the Earth to maintain a climate that can sustain life. Without the greenhouse effect, the Earth's climate would be cold and desolate. If the greenhouse effect is intensified by rising concentrations of greenhouse gases, the Earth will warm. Major greenhouse gases include carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Changing climate

Throughout geologic time, the Earth's climate has been in constant flux. Tropical forests have given way to massive ice sheets; oceans have dried up to become deserts. Recent studies demonstrate a strong link between changes in climate and the concentrations of greenhouse gases in the atmosphere. Since the industrial revolution, humans have been adding significant amounts of greenhouse gases to the atmosphere by burning fossil fuels for everything from generating electricity to powering cars (Figure 1). Greenhouse gases released by human activity remain in the atmosphere for 100 years or longer-in fact, carbon dioxide emitted by the first Model T Ford is still present in the atmosphere today.

FIGURE 1
Global CO_2 emissions



Global emissions of CO_2 from fossil fuel combustion have risen and continue to rise.
Source: Carbon Dioxide Information Analysis Center

Concentrations of the greenhouse gas carbon dioxide are increasing at a rate not seen in the past 20,000 years. Current carbon dioxide concentrations are higher than they have been in at least the past 400,000 years.[2] The greenhouse gases we emit today and in the future will only add to this already high concentration, resulting in even more rapid climate change.

Connecticut is part of the problem

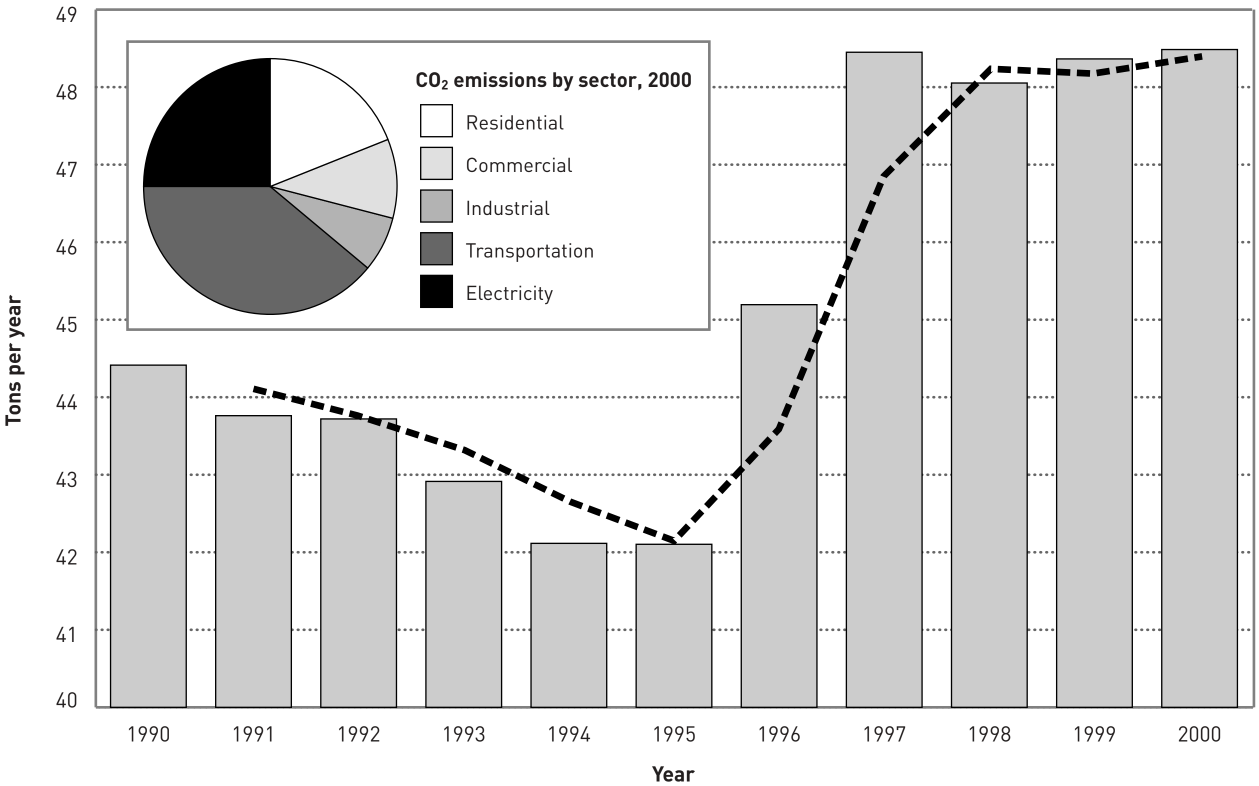
Connecticut contributes a significant amount of greenhouse gases to the atmosphere. In 2000, the state emitted the equivalent of 48 million metric tons of carbon dioxide (CO_2), a 9% increase from 1990 emissions.[3] In Connecticut, CO_2 accounts for 90% of total anthropogenic greenhouse gas emissions, with the majority of CO_2 emissions coming from the transportation sector (39%) and electricity generation (26%) (Figure 2).[4] In 2000, Connecticut emitted more CO_2 through the burning of fossil fuels than Venezuela and Chile combined.[5]

Many facets of life in Connecticut will be affected by climate change. Increased temperatures and precipitation will lead to a higher incidence of respiratory ailments such as asthma, vector borne-diseases and heat-related illnesses and death. The temperature increase resulting from climate change will also affect Connecticut's ecosystems, economy and infrastructure. Warmer waters have already contributed to the decline of lobster populations in Long Island Sound. Sea-level rise will cause erosion and flooding of coastal areas and wetlands, destroying local habitats and damaging infrastructure. All of these consequences will have a significant effect on the way of life of all Connecticut's residents and take a toll on the Connecticut economy.

Fortunately, we can take steps to lessen the impact of these changes and protect our homes and families. An obvious place to start reducing greenhouse gases is

FIGURE 2

Total greenhouse gas emissions for the State of Connecticut, 1990–2000



Source: Data from "Connecticut Greenhouse Gas Inventory, 1990–2000," NESCAUM, CTDEP, and CCEF, August 2003.

the transportation sector, which contribute 39% of Connecticut's total greenhouse gas emissions, the largest source in the state. By shifting to less-polluting fuels and more efficient vehicles, as well as addressing other polluting sources such as coal-burning power plants, Connecticut will cut greenhouse gas emissions, reduce its dependence on oil and improve the state's air quality.

CHAPTER 1

Connecticut's changing climate

The Earth's climate has changed many times throughout its history as a result of natural variations. Recently, however, humans have begun to alter the Earth's climate by releasing greenhouse gases such as carbon dioxide (CO_2) into the atmosphere. Our influence has been short-lived compared to the vast scale of the Earth's history, but the impact of our actions has been significant and rapid.

One of the key features of a changing climate is temperature. Changes in temperature affect local climates by influencing aspects of the climate system. For example, higher atmospheric temperature can influence precipitation in a particular region because higher temperatures affect water evaporation rates, which determine the water content of air masses. Though the relationship between temperature and precipitation is complex and not completely understood, the frequency of extreme weather events such as blizzards, heavy rain storms, ice storms and droughts appears to have increased in the northeastern U.S. since 1996, a period of substantial warming in New England.[6]

Atmospheric temperature also has significant effects on biological systems. Plants and animals have evolved over time to withstand the temperature fluctuations of their environment. As temperature range shifts, an organism's ability to survive and reproduce is altered. Some organisms may find the new conditions favorable and thrive. However, when rapid changes in climate occur, most organisms cannot adapt fast enough, and species may become extinct.

While a small change in the temperature on a given day may hardly be noticeable, a small long-term shift in temperature can have a great impact. At the height of the last Ice Age, New England was covered by a glacier two miles thick, but the average annual temperatures were estimated to be only 9°F cooler than today.[7]

Historical temperature trends

Connecticut's recent climate record, covering the past 100 years, depicts a gradual warming trend, with most of the highest annual temperatures on record occurring in the last decade. Connecticut is warming at a rate of 1–3°F per 100 years, an increase greater than the rest of New England.

We examined two climate datasets to explore changing temperatures in Connecticut. The goal was to search for trends in mean annual temperature profiles at specific temperature monitoring stations and within distinct climatic areas of the

TABLE 1

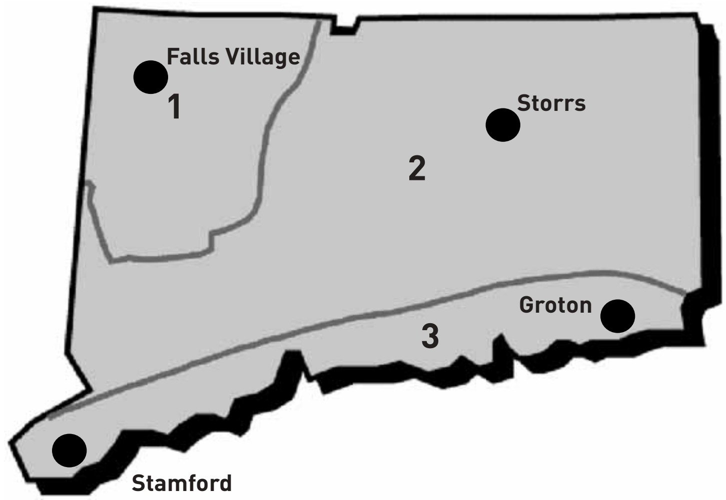
Connecticut USHCN station locations

All stations' time-series ended with year 2002

Station ID	Place	Elevation	Latitude	Longitude	Start
062685	Falls Village	550 feet	41° 57′	–73° 22′	1890
063207	Groton	40 feet	41° 21′	–72° 03′	1886
067970	Stamford	190 feet	41° 08′	–73° 33′	1892
068138	Storrs	650 feet	41° 48′	–72° 15′	1889

Source: Data from USHCN: ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/station.history.

FIGURE 3
Distribution of Connecticut's four USHCN monitoring stations and boundaries of the three climate divisions



Source: Modified from NCDC: www.ncdc.noaa.gov/img/onlineprod/drought/ct.gif.

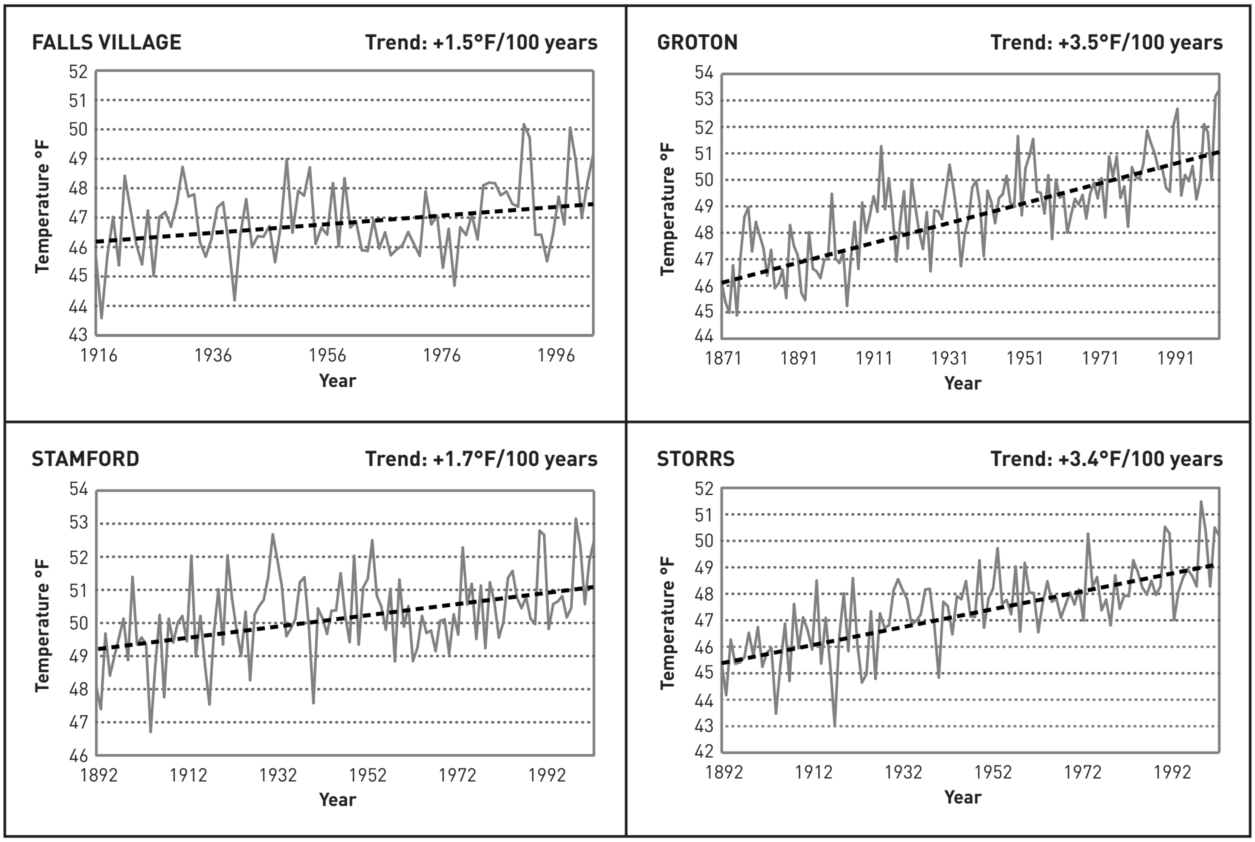
state. The National Climatic Data Center (NCDC) has assembled temperature monitoring station data as part of its U.S. Historical Climate Network (USHCN).[8] This network consists of 1,221 weather stations, of which four are in Connecticut (Table 1, Figure 3). Weather stations selected for inclusion into the USHCN had the following distinguishing characteristics:

- many continuous years of data collection
- few missing data points
- few and only minor changes in station location
- minimal factors affecting the compatibility of measurements over time

Adjustments have been made to the data records[9] to control for biases stemming from observation time-of-day, instrumentation changes and station moves. Temperature parameters from this dataset include mean, minimum and maximum temperature reported monthly. Annual temperature parameters for the four stations were estimated by averaging the 12 monthly values. For the four stations, the time-series began between 1886 and 1892 and ended in 2002.

Temperatures from U.S. Climate Division Data make up the second data set used in this analysis.[10] The data consist of monthly averages of temperatures from numerous cooperative weather stations covering an area considered climatically distinct from adjacent areas. Daily temperature records from all stations within a climate division are averaged together to produce a division-wide estimate of temperature. The NCDC recognizes three climate divisions within the state of Connecticut (Figure 3). Monthly mean temperature records were averaged to produce yearly average temperature values from 1931 to 2002. This data set is comprised of values averaged from all available stations within a climate division. Earlier data values (1895–1930) were available, but not included in this analysis because they do not represent comparable divisional averages to the post-1930 data series.

FIGURE 4
Mean annual temperature (°F) profiles from the four Connecticut USHCN stations.



The solid gray line represents temperature record. The dashed black line represents the average trend across all years in the time-series. All four stations show increasing mean annual temperatures with a range of 1.5°F (Falls Village) to 3.5°F (Storrs).

Source: Data from ftp://ftp.ncdc.noaa.gov/pub/data/ushcn.

The mean annual temperature profiles from all four USHCN stations report an increasing temperature trend over time (Figure 4). Profiles generated for mean annual maximum temperature (T_{max}), and mean annual minimum temperature (T_{min}), also demonstrated a trend toward increasing temperature over time (Table 2). The data suggest temperature increases have been greatest along the Connecticut south shore (Groton) and toward the eastern part of the state (Storrs), with the inland Falls Village site warming more slowly. The rates of temperature increase ranged from approximately 1° to 3°F every 100 years.

The 1930–2001 temperature profiles for the NCDC's three climate divisions corroborate the findings from the individual USHCN data (Figure 4). Over the same time period, the trend in mean annual temperature for the entire state of Connecticut (climate division area-weighted average) was +1.7°F per 100 years.

Climatic changes in temperature are not the same at all locations within any given region. In fact, large differences in temperature may exist among localities within a region. For example, the temperatures have risen faster in Storrs (3.4°F/100 years) than in Falls Village (1.5°F) (Table 2), even though these sites are not far from each other. Similarly, variations exist in the rate of temperature change throughout the northeastern U.S. Thus, Connecticut has experienced relatively greater warming than the average for the northeastern states.

TABLE 2

Annual mean, maximum, and minimum temperature (°F) trends at the four Connecticut USHCN stations

Annual temperatures have been increasing faster in Groton, Stamford, and Storrs than in Falls Village

Station	Mean temperature	Maximum temperature	Minimum temperature
Falls Village	+1.5	+1.3	+1.8
Groton	+3.5	+3.8	+2.8
Stamford	+1.7	+3.1	+1.4
Storrs	+3.4	+2.9	+3.5

Source: Data from NCDC: ftp://ftp.ncdc.noaa.gov/pub/data/ushcn/.

Land cover, land use and topography can all account for variability in temperature from place to place. A heavily fragmented landscape with patches of forest, agriculture zones, suburbs and urban centers will have greater differences in temperature change than a less fragmented landscape of homogeneous forest. If the landscape surrounding a monitoring station changes through time, a different trend can result than if the landscape remained constant. For example, many monitoring stations established in the early 20th century were initially located in more rural settings, and over time the environment surrounding the station became increasingly urbanized. Such a scenario could result in higher average rates of temperature increase compared to sites with fewer changes in landscape. Connecticut is part of the rapidly growing northeast "urban corridor," which probably explains its higher average temperature increase compared to the northeastern U.S. as a whole.

The long-term trends in Connecticut mean annual temperature all indicate that a gradual warming has occurred throughout the state over the past 70 to 100 years. The records also show the greatest mean annual temperatures have occurred over the past decade. The five highest mean annual temperatures reported at the four USHCN stations have generally occurred since 1990 (Table 3). Exceptions to this are the fifth highest record at Falls Village occurring in 1949, and high temperatures in 1931 and 1953 in Stamford. All five of Groton's and Storrs's highest annual temperatures have occurred since 1990.

Evidence indicates that Connecticut's south shore is warming faster than more inland areas. Connecticut climate division 3 has experienced an average rate of temperature increase approaching 3°F every 100 years, while the inland climate

TABLE 3

The five warmest years on record, 1931–2001

Highest mean annual temperature.

Falls Village		Groton		Stamford		Storrs	
1990	50.2	2002	53.4	1998	53.2	1998	51.5
1998	50.1	2001	53.2	1990	52.8	1990	50.5
1991	49.7	1991	52.7	1931	52.7	2001	50.5
2002	49.2	1990	52.1	1991	52.7	1999	50.4
1949	49.0	1998	52.1	1953	52.5	1991	50.3

Source: Data from NCDC: ftp://ftp.ncdc.noaa.gov/pub/data/ushcn.

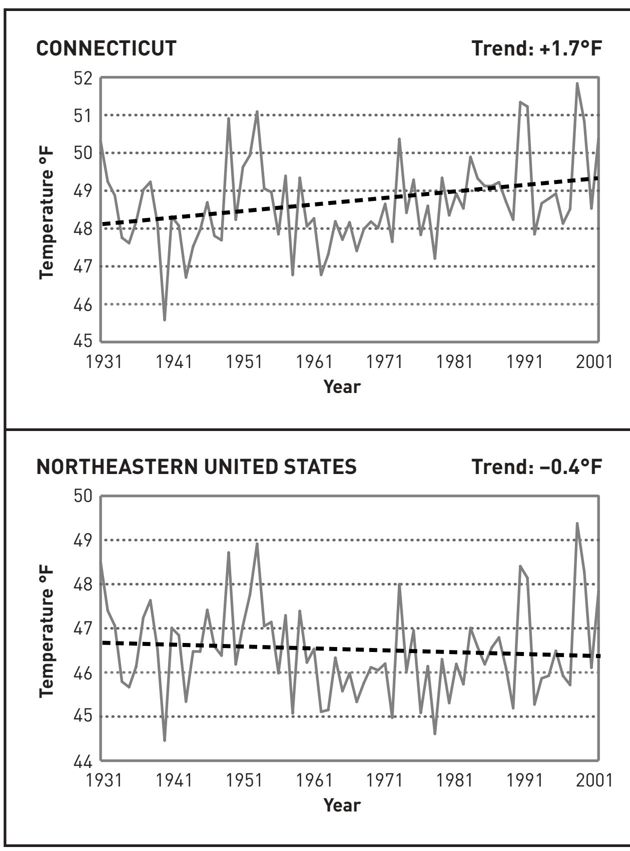
divisions 1 and 2 have increased at a slightly slower rate (Figure 5). The USHCN station in Groton, which lies on the southeast coast of the state has experienced a relatively high overall rate of increase, and its five warmest years have all occurred since 1990. Stamford, however, which also lies on the coast, has experienced more moderate increases in temperature.

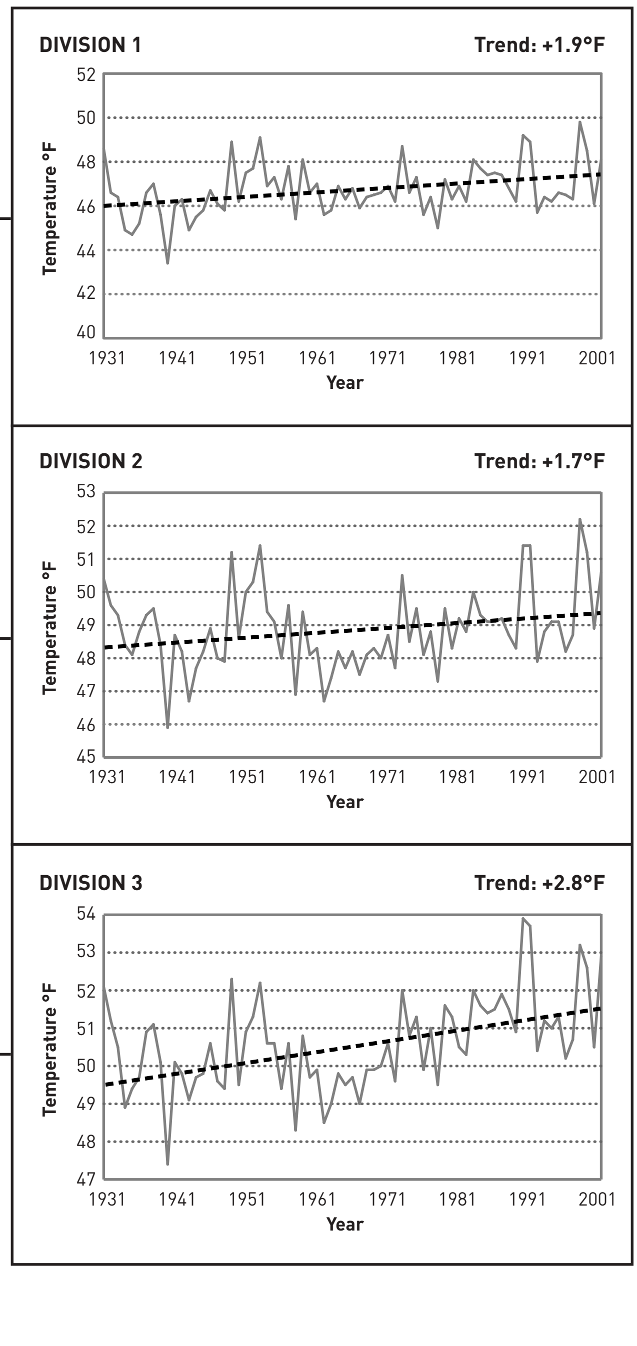
The station at Storrs, situated inland, has experienced the greatest warming trends among the four stations, and its five warmest years have occurred since 1990. Falls Village, located in the Northeast highlands of the state reported the lowest of all warming trends, but the climate division 1, within which it resides, posted the second highest warming trend among divisions. Thus, while it seems the southern coast of Connecticut is experiencing greater warming trends, the

FIGURE 5

Mean annual temperature (°F) for the three Connecticut climate divisions

The division area, weighted average for the entire state, and state area, weighted average for the Northeastern U.S. (including MD, PA, DE, NJ, NY, CT, RI, MA, VT, NH, and ME).





Source: Data from NCDC: www.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html high warming trend in Storrs, and relatively low warming trend in Stamford, fail to support a definitive spatial pattern in the statewide temperature trends.

Future temperature projections

Projections of future temperatures rely on mathematical models that describe how solar radiation and the atmosphere interact with ocean and land surfaces, as well as the amounts of greenhouse gases present in the atmosphere. Sulfate aerosols, another type of atmospheric pollutant, actually have a cooling effect by reflecting solar radiation back into space before it reaches the Earth's surface. The effects of both greenhouse gases and sulfate aerosols are taken into account in these models.

One type of climate model, called a general circulation model (GCM), has been used to simulate the effects of various future emissions scenarios, such as an annual 1% increase in atmospheric CO_2. Note that GCMs make predictions for very large areas (on the order of 56,000 square miles), far greater than the area of Connecticut (8,000 square miles). For this reason, future projections specific for Connecticut are unavailable. Researchers are developing finer scale models to make more localized estimates, accounting for an area's specific characteristics (landcover, topography, etc.).

In order to characterize potential climate changes for the New England region (including New York) the New England Regional Assessment[11] used two general climate models to determine approximate temperature ranges for New England by the year 2100. The use of two different models provides a more reliable estimate for the magnitude of future temperature increases. .

The models show that by the year 2030 mean annual temperatures may be expected to rise on the order of 2.5°F, and could increase as much as 4 to 9°F by the year 2100.[12] To put this in perspective, Hartford currently has an annual average temperature of 50°F. If Hartford's average temperature were to rise 4°, its average temperature would be the same as Philadelphia's. A 9°F increase would give Hartford the same average temperature as Raleigh. Temperatures could be expected to rise even further beyond 2100 as ocean temperatures slowly stabilize. The possibility also exists for abrupt, large changes in the climate, since the climate system does not always behave linearly.

There is no way to tease apart these projections to show how they relate to Connecticut specifically, because the temperature changes were estimated for the entire region. However, since Connecticut is part of the region, the projections do provide a generalized tool for considering future temperature ranges in the state.

The models used for the NERA report are based on the assumption that atmospheric CO_2 will increase 1% per year. That is, each year an additional 1% of the previous year's CO_2 is added to the atmosphere. This percentage increase reflects the current global rate of CO_2 emissions from the combustion of fossil fuels. However, it is not inevitable that CO_2 will increase by 1% per year. Global, regional and local initiatives to decrease CO_2 can slow or stabilize the temperature increases projected by the models.

CHAPTER 2

Impacts of temperature rise on human health

Climate change and human health

Climate change will have many significant impacts on human health. Rising temperatures will likely increase already unhealthy ozone levels in the state resulting in higher incidences of asthma and other respiratory diseases. In addition, increased temperatures may result in increased heat-related mortalities and an increase in vector-borne diseases.

OZONE

High up in the Earth's stratosphere, a layer of ozone gas (O_3) protects humans from harmful ultraviolet radiation from the sun. However, in the air that we breath, this same gas is a toxic pollutant that contributes to smog and harms health. The toxic form of ozone, often referred to as "ground-level ozone," is produced by a complex chemical reaction involving nitrogen oxides (NO_x), volatile organic compounds (VOCs) and sunlight.[13]

Ground-level ozone, or smog, is one of Connecticut's most persistent air pollutants. State efforts to restrict emissions have decreased ambient concentrations of the pollutant in the past decade, but days with dangerously unhealthy ozone levels remain all too common. The majority of NO_x in Connecticut is produced through the combustion of fossil fuel in motor vehicles and power plants, while VOCs are emitted from petroleum products and solvents used for industrial purposes, as well as from natural sources such as vegetation.

Ozone requires sunlight and warmer temperatures, so significant concentrations appear only in the warmer months (May through October). Although ozone production occurs in the daylight hours, characteristically peaking around midday, concentrations often remain elevated late into the evening, especially in areas downwind of major urban centers. As a result, downwind residents, such as those living along Connecticut's coastline, typically experience longer periods of unhealthy ozone levels.[14] In the summer, winds from the southwest carrying pollutants from industrial and metropolitan areas to the south and west parts of the state tend to coincide with high temperatures, providing the ideal conditions for smog formation.[15]

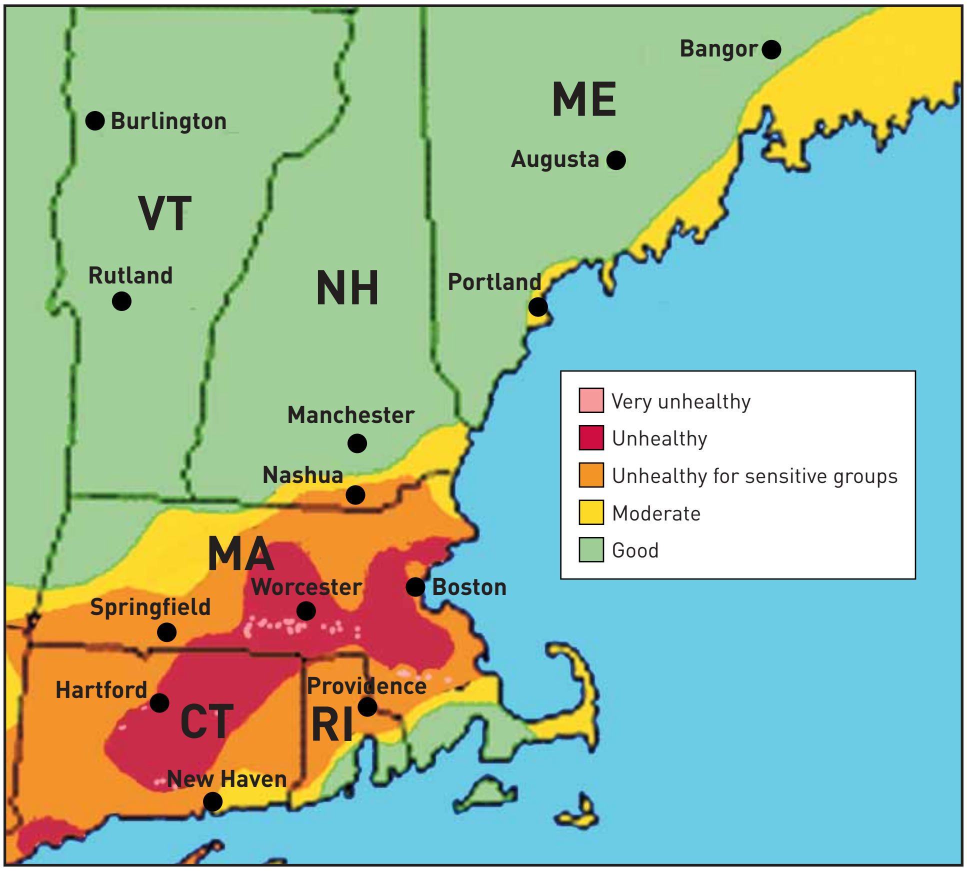
Connecticut has a long history of exceeding federal standards for healthy air, known as the National Ambient Air Quality Standards. Since 1990, Connecticut has averaged more than 25 days per year in which at least one region has recorded unhealthy ozone levels. An example of an ozone exceedance is illustrated in Figure 6, which shows ozone levels for a hot summer day in 1999. In 2001, Connecticut ranked third in the nation, trailing only California and Texas, for the highest "peak" concentrations of ozone above the one-hour federal standard. (The Environmental Protection Agency's one-hour standard requires that ozone concentrations not exceed 0.12 parts per million for any one hour period.[16]) In 2002, 179 violations of the stricter eight-hour standard occurred statewide. The eight-hour standard requires ozone concentrations averaged over an eight-hour period to be no higher than 0.08 ppm.[17]

Because the state has consistently exceeded national standards, Connecticut has been deemed out of compliance with federal air quality requirements and is classified

FIGURE 6

Connecticut leads New England in unhealthy air

Daily ozone level August 24, 1999



Source: USEPA. 1999. The Ozone Problem. www.epa.gov/region01/eco/dailyozone/oz_prob.html.

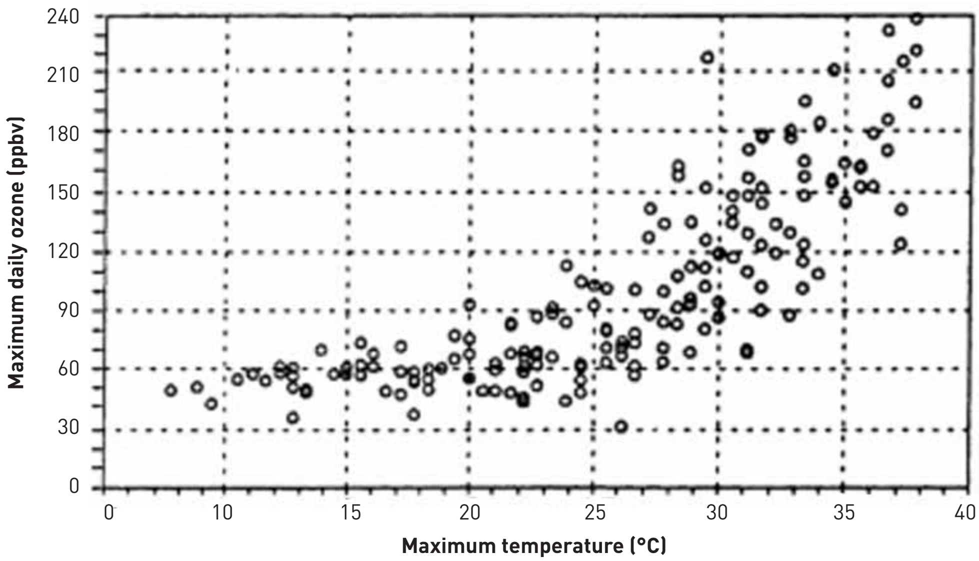
as a "non-attainment area." The southwest corner is classified as "severe," and the rest of the state is classified as "serious," making Connecticut's air the most unhealthy in the New England region. Impacts from climate change will only make Connecticut's struggle to achieve air quality standards even more challenging.

Climate change may affect ground-level ozone formation in many ways. Warmer temperatures are expected to enhance the formation of ground-level ozone by increasing the emissions of ozone precursors and the rate at which they react to form ozone. An increase in atmospheric temperature accelerates photochemical reaction rates in the atmosphere and increases the rate at which ozone is produced.[18] Emissions of VOCs from industry, mobile and natural sources are also temperature-dependent, with evaporative emissions from petroleum products and chemical solvents increasing as temperatures rise.[19] Natural sources will also emit greater amounts of VOCs as respiration rates of vegetation rise in the warmer climate.

Humans also will have an impact on ozone levels as their behaviors change in reaction to rising temperatures. Increased use of air conditioning will boost energy demands, and if this demand is fed by burning fossil fuels, increased emissions of NOx and VOCs will lead to even higher ozone levels. Changing weather patterns may also affect ozone, as high temperatures are often associated with high baro-

FIGURE 7

As temperatures rise, so do maximum ozone levels in New York City



Source: USEPA. 1991. Aerometric Information Retrieval System (AIRS). Research Triangle Park, NC.

metric pressure, stagnant circulation and suppressed vertical mixing, all of which may contribute to elevated ozone levels.[20] However, the exact impact of climate change on weather patterns is still unclear.

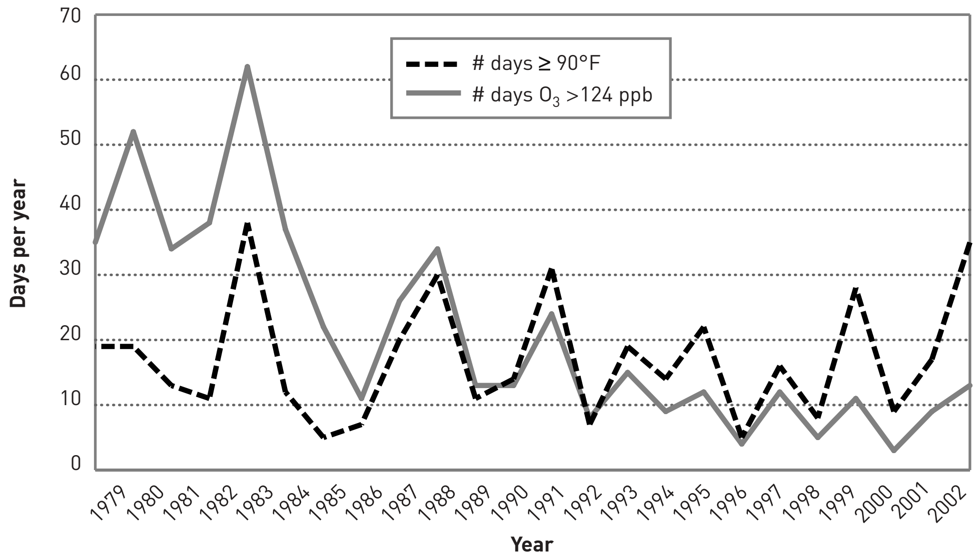
Many studies have highlighted the correlation between ground-level ozone and temperature. Sophisticated climate models, simulated smog chamber studies and observations of temperature and ozone patterns at sites across the United States all have shown that ozone formation is highly dependent on temperature. One study modeled the impact of global warming on ozone concentrations on the Northeastern United States and found that a uniform increase in temperature of 7°F would result in an almost 20% increase in ozone concentrations.[21] Using observed data from both urban and polluted rural areas, Sillman and Samson (1995) found that ozone increases with temperature at an even faster rate than predicted by the models.[22]

Temperature and ozone data from the New York-New Jersey-Connecticut metropolitan region collected by the EPA during the summer of 1988 show a strong correlation between maximum daily temperature and peak ozone concentrations in the higher temperature ranges (Figure 7).[23] Smog chamber studies have confirmed this relationship.[24]

Historical trends in temperature and ozone for Connecticut also demonstrate this correlation. Measurements taken at Bradley International Airport in Windsor Locks from 1979 to 2002 show that years where the one-hour ozone standard was often exceeded were also years with an exceptional number of days with extreme high temperatures (Figure 8).[25] State efforts to decrease emissions have helped curb ozone levels over this time, with reductions of 50 percent or greater in some cases, leading to fewer high ozone days.[26] However, climate change is projected to increase the number of days with high temperatures, jeopardizing the gains made in reducing Connecticut's unhealthy ozone levels.

FIGURE 8

Annual number of hot days (T>90°F) at Bradley International Airport vs. number of high ozone days (O_3 >12ppb anywhere in CT) 1979–2002



Source: Connecticut Department of Environmental Protection

HEALTH EFFECTS ASSOCIATED WITH GROUND-LEVEL OZONE

Exposure to elevated levels of ground-level ozone has been shown to cause a variety of harmful impacts, many of which are likely to become more severe as a result of climate change. When inhaled, ozone damages protective cell membranes, causing inflammation and impairing lung function.[27]

Some of the most common acute effects of exposure to high ozone levels are severe coughing, shortness of breath, pain when breathing, lung and eye irritation and a greater susceptibility to respiratory illness such as bronchitis and pneumonia.[28] Most of these effects are considered to be short-term because they cease once exposure to elevated levels of ozone ceases. However, scientists are concerned that repeated short-term damage from ozone exposure may permanently injure the lung, especially the developing lungs of children, which can lead to reduced lung function as adults. Ozone exposure may also accelerate the decline in lung function that occurs as a natural result of aging.[29]

Several studies have shown that brief exposures to ozone above 80 parts per billion (the national ambient eight-hour standard) cause drops in lung volumes, impairment of lung function and inflammation.[30] Connecticut had 36 days exceeding this level in 2002, many of which occurred along the southwest coast, endangering the health of hundreds of thousands of residents.[31] Summer hospital admissions for respiratory ailments were associated with high ozone levels in a study of respiratory illness in Ontario.[32] In 1997, there were 2,610 emergency room visits for ozone-related respiratory problems in Connecticut, and over 1,400,000 people who complained of minor respiratory symptoms due to ozone.[33]

People exhibit many different responses to ozone exposure, ranging from no response at all to responses many more times severe than the average population experiences. Even moderately exercising healthy adults can experience a 15 to 20% reduction in lung function from exposure to low levels of ozone over several hours.[34] Although everyone is susceptible to the harmful effects of ozone exposure, those particularly at risk are children, the elderly and those suffering from respiratory and cardiovascular conditions.[35]

ASTHMA

Especially troubling is the link between ozone and asthma, a chronic inflammatory disorder of the lungs characterized by episodic symptoms of airflow obstruction. Studies have shown asthmatics to be especially vulnerable to ozone, which exacerbates existing symptoms and triggers attacks. [36] A study of ozone-levels and daily asthma hospital admissions in the New York Metropolitan area found that ozone accounted for between 12 and 24% of asthma admissions. [37]

Asthma is reaching almost epidemic proportions in much of the United States, affecting over 20 million people, including over 6 million children, in 2001.[38] The overall death rate from asthma in the United States is up 15% over the last decade, and up 60% in the last two decades.[39] Connecticut's 2001 asthma rate surpasses the United States average, with 7.8% of Connecticut adults affected by asthma compared to only 7.1% for the whole United States.[40] That adds up to more than 200,000 adults and 75,000 children across the state.[41]

The prevalence of asthma is highest in children, with as many as 8.9% of Connecticut's children affected. Asthma is the leading serious chronic illness among children and the third leading cause of hospitalizations among children 15 years and younger.[42] The asthma hospitalization rate for children in Connecticut was almost half that for children in the United States as a whole in 2000. However, the rate for children in Connecticut's five largest urban areas (Bridgeport, Hartford, New Haven, Stamford and Waterbury) was 20% higher than the national average. Although only approximately 20% of Connecticut's children aged 14 and younger live in the state's five largest cities, children in these cities accounted for nearly 45% of all asthma hospitalizations and emergency room visits in 2000.[43]

Asthma data for the state also raise environmental justice concerns. In Connecticut, the prevalence of asthma is closely associated with household income, with the highest rate of asthma seen in households making less than $25,000 per year. For this income category, asthma rates reached 11.5% for adults and 13.5% for children in 2001, much higher than the state average.

Asthma also disproportionately affects ethnic minorities. From 1992 to 2000, asthma hospitalization rates for black and Hispanic children were consistently

TABLE 4

Asthma takes a toll on Connecticut counties

CT county	Adults with asthma	Children with asthma	Total costs
Fairfield	52,302	12,510	$33,935,000
Hartford	51,192	11,659	$34,388,000
New Haven	49,434	11,153	$32,637,000
New London	15,677	3,497	$10,138,000
Litchfield	10,844	2,480	$7,198,000
Middlesex	9,480	1,990	$5,943,000
Tolland	8,540	1,743	$5,368,000

Source: Asthma and Allergy Foundation of America. 1998. The Costs of Asthma in Connecticut. www.aafa.org/states/display.cfm?State=ct higher than for white children. The hospitalization rate for black children was nearly five times higher than the average annual rate for white children in the state. [44] Multiple reasons exist for such a high incidence of asthma among minority populations, including limited access to proper medical treatment and poor living conditions. However, increasing ozone levels could cause even more harm to an already vulnerable community.

Although it is impossible to calculate the costs asthma has imposed on the health of Connecticut residents, the costs to Connecticut's economy are quantifiable. In 1998, treatment of asthma cost the residents of Connecticut approximately $134 million, in both direct medical expenditures and indirect costs.[45] Counties with large urban areas bore the brunt of the costs, with Fairfield, Hartford and New Haven each shelling out more than $30 million to combat asthma that year (Table 4).[46]

Heat-related illness and death

Over 14,000 people died during a blistering heat wave that hit Europe in the summer of 2003.[47] Parisian undertakers worked overtime as the death rate jumped 37% from weeks prior to the heat wave.[48] While scientists cannot directly attribute Europe's sweltering temperatures to climate change, it is becoming increasingly clear that climate plays an important role in such extreme weather events. The World Meteorological Organization (WMO), in its press release addressing the heat wave, stated "new record extreme events occur every year somewhere in the globe, but in recent years the number of such extremes has been increasing. . . . Recent scientific assessments indicate that, as the global temperatures continue to warm due to climate change, the number and intensity of extreme events might increase."[49]

We have shown that rising temperatures due to climate change indirectly increase ozone and make people sick, but warmer temperatures, and especially extreme heat events, can kill as well. The most direct impact of heat on the human body is heat exhaustion and heat stroke, but the most serious impact of heat is that it can greatly increase the risk of death from preexisting cardiovascular and respiratory disease, or stroke.[50] During hot weather, the total death rate, especially from cardiovascular disease, may be more than double the average long-term rate.[51]

Regions most vulnerable to increased death rates during extreme weather events are those least able to adapt. People whose bodies are accustomed to warmer temperatures and whose living environments are better equipped to provide relief from the heat will be better able to acclimate to extreme weather. Models of weather-mortality relationships indicate that populations in northeastern U.S. cities are likely to experience the greatest number of heat-related illnesses and deaths in response to changes in summer temperature.[52] A recent study examined time-series analyses of 12 U.S. cities, including New Haven, to estimate the effects of temperature on respiratory and cardiovascular disease deaths. Data showed that for cities in warm climates, high temperature had little effect on mortality rates. However, for cities like New Haven located in colder climates, high temperatures were associated with significant increases in deaths from cardiovascular and respiratory disease.[53]

Elderly populations and low-income groups are most vulnerable to heat stress and will be more likely to suffer from the added stresses of climate change. The

Connecticut's car trouble

Driving a car is one of the most polluting activities we do each day. Although emission-control technology has improved over the years, vehicles still emit a significant amount of pollution. The increasing popularity of heavier, more powerful vehicles has meant that average greenhouse gas emissions from passenger vehicles are essentially unchanged from 20 years ago. A car-and-truck fleet that gets fewer miles to the gallon uses more fuel and emits more pollution. At the same time, the number of cars on the road and the miles they travel has doubled nationwide.

In the United States, the transportation sector is the largest single contributor to greenhouse gas emissions emitting 511.6 million metric tons of carbon equivalent in 2001-almost one-third of the total U.S. emissions.[66] Though diesel trucks and other large vehicles are the dirtiest on the road, the sheer number of passenger vehicles and the thousands of miles they travel make passenger vehicles the largest transportation source of greenhouse gases. Passenger cars and trucks emit 61% of transportation greenhouse gas emissions.[67]

Compared to the national average, the transportation sector in Connecticut contributes more greenhouse gas emissions as a percentage of the total.[68] In 2000, transportation in Connecticut accounted for 39% of that state's emissions, up from 35% in 1990.[69] This trend is expected to continue because of the steep increase in the number of miles driven, measured in vehicle-miles traveled (VMT). Connecticut saw a 16% increase in VMT between 1990 and 2000, while the population grew only 3.5%. Passenger vehicles will be driven about 80 million miles on the state's roads and highways this year. By 2025, this number could increase almost 25% to about 99 million miles.[70] Greenhouse gas emissions will also rise unless actions are taken to make vehicles less polluting.

In addition to greenhouse gases, motor vehicles also spew out a number of dangerous chemicals that pollute the air and endanger human health. In Connecticut, highway motor vehicles are responsible for more than 40% of toxic air emissions—those that cause cancer and other serious health impacts.[71] Connecticut's vehicles are also a major source of the chemicals that react to form ozone smog, emitting nearly half of all nitrogen oxide (NO_x) emissions and nearly a third of volatile organic compound emissions (VOCs).[72] In fact, according to the Surface Transportation Policy Project's recent report "Clearing the Air," Hartford was ranked the seventh worst metropolitan area in the nation for per capita emissions of smog-forming pollutants in 1999, with 742 tons per person emitted by cars and heavy-duty vehicles.[73]

The technology exists to cut pollution and global warming emissions, but automakers have opposed such measures. Unless government rtakes steps to speed the adoption of these technologies and consumers demand vehicles that offer them, automakers will continue to produce cars and trucks that threaten health and harm the environment.

elderly are especially susceptible to death from heat stress due to pre-existing cardiovascular and respiratory disease, as well as greater risk of stroke. In the Chicago heat wave during the summer of 1995, in which over 700 people died from heat stress, elderly individuals over the age of 65 accounted for 72% of all deaths.[54,55] The elderly population in Connecticut is projected to increase almost 50% by 2025. At the same time, the state's heat-stress mortality risk is expected to increase.[56]

Living in urban centers increases the risk of heat stress for the elderly, low-income communities and people of color, all of whom have more limited access to air-conditioning, adequate medical care and other resources. Temperatures in cities can be up to 6 to 8°F hotter than surrounding areas.[57] This "urban heat island" effect is caused by concrete and other materials that absorb heat during the day and radiate this heat during the night, exacerbating heat stress for urban residents. Findings from the Chicago heat wave and early findings from Paris both indicate that if the elderly had been better warned and cared for, many heat-related deaths could have been prevented. Early warning systems and increased public education about adapting to the heat are ways to reduce heat-related deaths.

A recent study by Physicians for Social Responsibility surveyed National Oceanographic and Atmospheric Administration (NOAA) weather data and found that in 2000 about twice as many high-heat-stress days (those with temperatures over 90°F) occurred on average than in 1948. The nationwide incidence of four-day heat waves has nearly tripled, and unusually warm nights are twice as common as they were in the 1950s.[58] In fact, data from NASA's Goddard Institute for Space Studies for the four USHCN stations in Connecticut project that in the 2050s, there will be on average almost 10 more high-heat-stress days per year than in the 1990s.[59] For the city of Groton, the number of high heat stress days will nearly quadruple.[60]

Historic temperature data from the four Connecticut USHCN stations has shown an average increase in annual mean temperature of 2.6°F. Average minimum and maximum annual temperatures have increased 2.4 and 2.8°F respectively. Studies show an association between increased death rates and increases in minimum temperature. Kalkstein observed that minimum temperature played a key role in heat-related mortality risk: Whereas cooler nighttime temperatures usually lessen the effects of hot daytime conditions, high over-night temperatures exacerbate the stress of extremely hot days.[61]

Increases in maximum temperatures also increase heat-related death rates, which are at their highest when temperatures exceed normal limits.[62] In a 1997 study examining climate-mortality relationships in large U.S. cities, Kalkstein found that for the average summer season in New Haven, deaths from heat stress will increase 8–32% by 2050 according to different global climate models.[63]

Numerous studies demonstrate the link between climate change and summer season death rates, but the impacts of climate change on winter death rates remain uncertain. It has been suggested that milder winters could reduce deaths; however, the relationship between winter temperatures and mortality is unclear. Many other factors impact winter mortality rates, such as influenza and pneumonia, as well as accidents caused by hazardous driving conditions. It is unclear how an increase in minimum temperature would affect these factors.[64] Global climate models predict no significant change in winter mortality rates for New Haven for the years 2020 and 2050.[65]

Vector-borne disease

Climate change could also influence the health risk from vector-borne diseases such as West Nile Virus, Lyme disease and malaria. These diseases are transmitted between humans and animals by blood-feeding insects and other transmitters known as "vectors." The rate of transmission is often influenced by changes in the vectors' environment. As temperatures rise, the habitats and breeding patterns of

New Haven thinks globally and acts locally

Connecticut's policymakers have been leaders in addressing climate change. In August 2001, Governor Rowland joined the Conference of the New England Governors and Eastern Canadian Premiers in adopting the Climate Change Action Plan that calls on states and provinces to increase energy efficiency and renewable energy use and reduce pollution from the power and transportation sectors. The governors and premiers committed to reduce regional greenhouse gas emissions to 1990 levels by 2010 and to at least 10% below 1990 levels by 2020. Connecticut also is participating in an effort led by New York's Governor Pataki to address regional greenhouse gas emissions from power plants, with a goal of reaching agreement by 2005.

On a local level, 32 cities in New England and six Connecticut cities are active in the Cities for Climate Protection Campaign sponsored by the International Council for Local Environmental Initiatives. New Haven stands out as an example. Local air quality concerns have motivated the city to help address a global problem, and the city's mayor, John DeStefano, Jr., has made climate change a high priority. In 2001, New Haven completed an inventory of its greenhouse gas emissions that highlighted opportunities to save energy. Since the late 1990s, New Haven has pursued aggressive steps to conserve energy, investing in lighting and ventilation improvements and LED (low-emitting diode) traffic lights. The city recently completed a comprehensive energy audit of all public buildings and schools and expects to make further improvements in energy conservation. Conservation measures already are saving New Haven about $3 million per year out of a $14 million energy budget, and the city has been awarded Connecticut's Green Circle Award for energy efficiency measures.

Despite improvements, energy demand is expected to rise due to an aggressive school construction and renovation program. In order to reduce the demand, New Haven has commissioned a "high performance schools" design guide. The guide sets standards for environmentally friendly construction and energy conservation modeled on national standards.

The city also is moving beyond conservation to encourage cleaner power. When Connecticut nonprofits SmartPower and the Connecticut Climate Action Project organized a campaign asking state government to purchase 20% of its power from clean or renewable sources by 2010, the city immediately pledged its support. In June, the New Haven Board of Aldermen passed a resolution supporting the statewide "20% by 2010 Campaign." Mayor DeStefano has formed a Clean Energy Choices Task Force to investigate ways the city can reach the goals of the campaign. According to the mayor's office, New Haven is already on the way. The city soon will draw 2% of its power from an industrial-size, non-polluting fuel cell, and a project is beginning that will generate renewable power using waste from the New Haven landfill. The city is also prioritizing opportunities in town to develop renewable power, such as solar panels on public schools.

New Haven also has launched efforts to address pollution from the transportation sector. A compressed natural gas station recently was installed to fuel city vehicles. Last year, in conjunction with the Greater New Haven Clean Cities Coalition and the Greater New Haven Transit District, the city commissioned a fleet of electric trolleys that operate in downtown New Haven. The trolleys will soon be charged by a non-polluting fuel cell. Greenways and bikeways now being planned will provide additional transportation alternatives.

In the fall of 2004, the city will establish a target for greenhouse gas reductions and develop an action plan to meet that target. This will involve quantifying the benefits of current projects and proposing new initiatives.

insects and rodents may be altered, bringing them into closer contact with humans and increasing the risk of disease transmission.

Studies have shown the transmission rate of vector-borne disease to be temperature-dependent, increasing with warmer weather.[74] Most vector-borne diseases are seasonal, occurring during the warmer months when insect populations thrive and humans spend more time outdoors. Higher temperatures have been found to accelerate insect maturation and pathogen development rates, and milder winters and extended summer seasons may allow for longer breeding seasons, all increasing the opportunity for transmission.[75] Climate change may allow vectors and the diseases they carry to spread to areas where they did not previously exist. Warming temperatures in temperate areas like Connecticut may lead to the appearance of diseases formerly associated with warmer areas of the globe, such as West Nile virus and malaria.

WEST NILE VIRUS

Just as it seemed like the United States had eradicated many serious infectious diseases, such as small pox and polio, new exotic diseases started cropping up. First discovered in Uganda in 1937, West Nile virus has made its way here, first appearing in 1999 in New York and New Jersey, and spreading quickly to other states. West Nile virus is spread to humans by the bite of a mosquito, which usually becomes infected after biting a bird that carries the virus. Mild infections in humans cause fever, headache and body aches, while severe infections can lead to neck stiffness, disorientation, coma, tremors, convulsions and paralysis. About 3–15% of infected individuals who develop these symptoms die from the disease.[76] In the past two years in the United States, 350 people have died from West Nile virus.[77]

In Connecticut, 26 people have been infected with the West Nile virus since the first U.S. outbreak occurred in 1999.[78] In 2002, more than 520 birds collected from all eight counties in Connecticut tested positive for the virus.[79] Rising temperatures and a shift in mosquito habitat could mean higher infection rates in the future.

EASTERN EQUINE ENCEPHALITIS

Another deadly disease spread by mosquitoes in the Northeast, Eastern equine encephalitis (EEE) infects mainly horses, but can also be fatal in humans. Symptoms in humans start to appear within 4–10 days of infection. They include sudden fever, general muscle pains and a headache of increasing severity, often progressing to more severe symptoms such as seizures and coma. Approximately one-third of all people with clinical encephalitis caused by EEE will die from the disease, and of those who recover, many will suffer permanent brain damage.[80] There have only been four cases of EEE in Connecticut, all in horses, but the incidence of infection may increase as the environment becomes more hospitable to the insects that transmit the disease.[81] In September of 2003, the Connecticut Department of Environmental Protection announced it had captured mosquitoes infected with EEE for second time in North Stonington.[82]

MALARIA

Malaria today is found principally in the tropics; however, favorable conditions in other areas suggest that the disease could occupy a larger range. For the past 20 years

Connecticut has averaged around 22 cases of malaria per year, with a high of 43 cases in 1998. [83] Although most of these cases were likely brought home to Connecticut by residents traveling abroad, the changing climate of the region could lead to a greater incidence of infection within the state. The type of mosquito that transmits malaria, the Anopheles mosquito, already exists in Connecticut, and warmer temperatures could lead to population increases. Warming could also lead to greater transmission rates, as the rate of development of the parasite in the mosquito is also temperature controlled.[84] The World Health Organization projects that an increase in average global temperatures of several degrees by the year 2100 could increase the capacity of mosquitoes to transmit the disease 100-fold in temperate regions like Connecticut.[85]

DENGUE FEVER

Like malaria, dengue fever is considered a tropical disease and is mainly introduced into the United States by travelers. However, health officials have determined that the disease has been established in southern Texas, and insects that have the potential to carry dengue fever have spread as far north as Chicago. The range and number of the dengue-transmitting mosquito *Aedes aegypti* have grown rapidly since the 1970s when a U.S. eradication program was discontinued.[86] The EPA warns that climate change may increase the potential for dengue-spreading mosquitoes in more northern latitudes of the United States.[87] Also known as "breakbone fever," the main symptoms of dengue are high fever, severe headache, backache, joint pains, nausea and vomiting.[88]

LYME DISEASE

Ticks are another insect that can transmit disease when they bite humans, spreading bacteria that cause Lyme disease. Lyme disease is the most commonly reported vector-borne disease in the United States, with more than 16,000 cases reported each year.[89] Those infected usually display a rash where bitten, followed by fever, fatigue, muscle and joint aches. If left untreated, Lyme disease causes chronic conditions such as arthritis, neurological and cardiac problems.

The black-legged tick that transmits the disease lives primarily in the northeastern U.S., with over 90% of Lyme disease cases reported in this region. In 2000, Connecticut had the highest reported rate of Lyme disease of any state, with over 110 cases per 100,000 people. Windham county reported the highest rate with 330 cases per 100,000 people.[90] The incidence of Lyme disease has increased 100 times since 1987, when reporting of the disease became required. Over 22,300 cases were reported in 1999.[91]

In Connecticut, over three-quarters of Lyme disease cases are reported during the summer months when warm weather allows tick populations to thrive and people spend time outdoors.[92] Changes in climate may cause the incidence of Lyme disease to increase. In a study of black-legged ticks in New Jersey, scientists found that temperature and humidity accounted for most of the variation in tick breeding and behavior.[93] Warmer winter and spring temperatures may lengthen tick season, prolonging exposure and increasing the risk of transmission of the disease.

HANTAVIRUS

Rodents can also act as vectors that transmit disease to humans, who become exposed by breathing dust containing particles of urine, droppings and saliva of an infected rodent. In recent years, sporadic cases of rodent-borne disease have been reported in the Northeast, with hantavirus posing the biggest threat to Connecticut residents. Hantavirus Pulmonary Syndrome is characterized early on by flu-like symptoms, with respiratory problems worsening rapidly after several days as the lungs fill with fluid.[94] Of all reported cased, 38% result in death.[95] No known cure exists.

Many scientists attribute the emergence of the disease in the United States to changes in climate. Scientists have linked the 1993 hantavirus outbreak in the Southwest to extreme weather and temperature events. An explosion in rodent populations occurred when above-average precipitation from the 1991-92 El Niño event increased their food supply.[96] A subsequent drought suddenly reduced the food supply, leaving the inflated rodent population to compete for food. The conditions increased contact between rodents and humans, resulting in a higher chance of disease transmission. Changes in weather patterns, a higher incidence of extreme weather and more El Niño-type conditions associated with climate change could lead to more such outbreaks.

REDUCING RISK

Steps can be taken to reduce the risk of vector-borne disease. The Connecticut Department of Environmental Protection and Department of Public Health have instituted the Connecticut Mosquito Management Program (MMP), which is responsible for monitoring and managing the state's mosquito populations to reduce the threat of mosquito-borne disease.[97] Through public education and infection warnings, as well as through biological and chemical control, the MMP can help Connecticut residents reduce their risk of infection. Continued management will be necessary to protect Connecticut residents as climate change makes vectors and the diseases they carry more prevalent.

CHAPTER 3

Impacts of sea-level rise on Connecticut

Chapter 3 was written by Vivien Gornitz and Cynthia Rosensweig

Sea-level rise

During the 20th century, the Earth warmed by about 1˚F.[98] The increase in temperature has resulted in the most rapid rate of sea-level rise within the last few thousand years.[99] The melting of mountain glaciers and of the Greenland ice sheet has contributed to the observed 0.04–0.08 inch per year rise in global mean sea level over the past 100 years.[100] In addition, ocean temperature increased 0.1F° between 1955 and 1996. Since warmer water occupies a larger volume than colder water, ocean levels have been rising an additional 0.02 inches per year.[101]

Sea level has not gone up uniformly everywhere. Adjustments of the Earth's crust to the removal of the ice sheets (known as glacial isostasy), and local land subsidence affect the ocean level. Tectonic forces such as mountain building also affect global ocean levels. Because the magnitude of these processes varies from one place to another, local sea-level trends may differ considerably from the global mean value.

Accelerated sea-level rise caused by global warming would greatly amplify already at-risk coastal populations. By the end of this century, a two- to five-fold increase in rates of global sea-level rise could lead to the inundation of low-lying coastal regions, more frequent and more extensive flooding due to storm surges, worsening beach erosion and the increasing salinization of coastal aquifers and estuaries.

In Connecticut, as elsewhere, the coastal zone is squeezed between sea-level rise and the resulting natural hazards on the one hand, and development pressures on the other. Between 1960 and 1995, populations in the four coastal counties of Connecticut soared, with increases from 21% (New Haven Co.) to 65% (Middlesex Co.).[102] In addition, important infrastructure lies close to the shore, including major transportation corridors such as the Connecticut Turnpike (I-95) and parts of the Amtrak railroad. As coastal population densities increase, greater numbers of people and assets will be placed in harm's way.

HISTORIC SEA-LEVEL TRENDS

At the height of the last glaciation, around 20,000–25,000 years ago, an ice sheet several miles thick covered Connecticut and spread as far south as Long Island. The sea level was around 400 feet lower than at present. When the glaciers began to retreat 18,000 years ago, the sea level began to rise. This sea-level rise associated with melting glacial ice continued until approximately 6,000 years ago. During the last glaciation, the weight of the ice sheet caused the Earth's crust to warp and Connecticut to be slightly uplifted. Now that the ice sheet has melted, the Earth's crust is evening out, and Connecticut is slowly sinking at approximately 0.03-0.035 inches per year (Table 5).[103] This is known as glacial isostatic adjustment.

Modern sea-level trends are recorded by network of tide gauges maintained by the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service.[104] The gauges measure *relative* sea-level change, which includes glacial isostatic adjustments and other geologic signals.[105] Removing these geologic trends from the relative sea-level curve leaves the *absolute* sea level change. The absolute sea level change is due primarily to climate changes.

TABLE 5

Relative sea level trends: Connecticut, New York, New Jersey tri-state region

Station	Relative sea level rise inches/year	Record length years	GIA correction inches/year
New London, CT	0.08	1938–1999	0.03
Bridgeport, CT	0.10	1964–1999	0.03
Montauk, NY	0.10	1947–1999	0.04
Port Jefferson, NY	0.10	1957–1992	0.04
Willets Point, NY	0.09	1931–1999	0.04
New York City, NY	0.11	1856–1999	0.04
Sandy Hook, NJ	0.15	1932–1999	0.04
Atlantic City, NJ	0.16	1911–1999	0.05
Cape May, NJ	0.15	1965–1999	0.05

Source: Peltier, W.R., 2001. Global isostatic adjustment and modern instrumental records of relative sea level history. In: B.C. Douglas, M.S. Kearney, and S.P. Leatherman, eds., *Sea Level Rise: History and Consequences.* Academic Press, San Diego, p. 65–95.

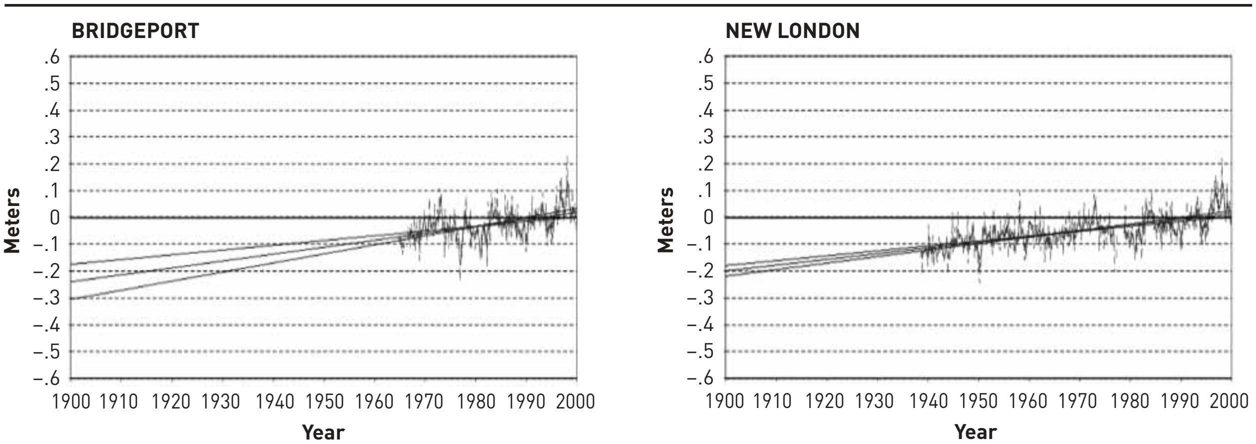
Present rates of relative sea-level change in the tri-state region range between 0.08 and 0.16 inch per year (Table 5). In Connecticut, the current rates are 0.10 inch per year (Bridgeport) and 0.08 inch per year (New London) (Figure 9). These trends exceed the global mean trend of sea level rise of around 0.06 ± .02 inch per yr.[106] The rates are higher as a result of the glacial isostatic-induced subsidence mentioned above (Table 5).

FUTURE SEA-LEVEL RISE PROJECTIONS

In 2001, the Unites States Global Climate Change Research Program released a climate change impacts study for the metro East Coast as part if the National Assessment of Climate Change Impacts on the United States.[107] We briefly review the regional sea-level rise projections as described in this report.[108] These projections included outputs from two global climate models: the Canadian Centre for Climate Modeling and Analysis and the United Kingdom Hadley Centre.[109] Each of

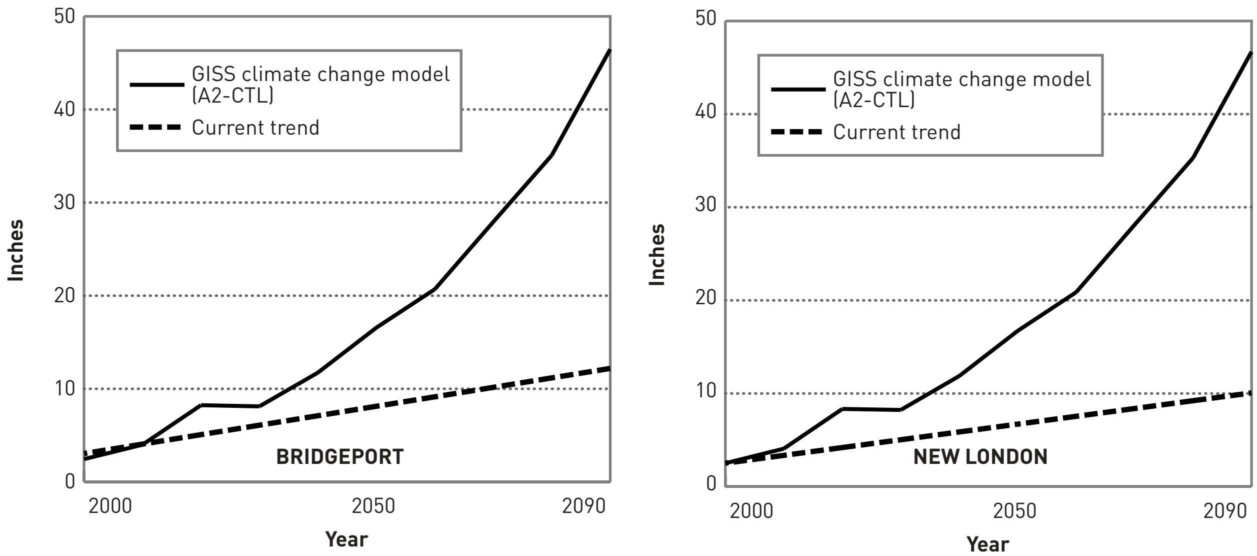
FIGURE 9

Mean sea level trends—Bridgeport and New London



Source: NOAA National Oceanic Service Center for Operational Oceanographic Products and Services http://140.90.78.170/sltrends/sltrends_states.shtml?region=ct

FIGURE 10
Sea level rise projections for Bridgeport and New London (inches)



these models includes two possible scenarios: one which takes into account greenhouse gases only (the GG scenario), and one which takes into account greenhouse gases plus sulfate aerosols, which have a cooling effect (the GS scenario). The Metro East Coast report also includes a linear extrapolation of historic (last 100 years) sea-level trends from tide-gauge data.[110] Although the study projected only a small increase in sea level within the next two to three decades, levels could climb by as much as 7-24 inches by mid-century, and up to 9–43 inches by the 2080s.

In this report, we use two scenarios to create new projections of sea-level rise for Bridgeport and New London (Figure 10). Sea levels are calculated as 10-year mean values above the average value for the base period (1961–1990) in order to minimize year-to-year variations.

This study uses two sea-level rise scenarios. One is based on current sea-level rise trends and represents a conservative estimate of future sea-level rise, assuming that current trends will continue without future changes from global warming.[111] The other scenario, based on a Goddard Institute for Space Studies climate model scenario A2-CTL, assumes high CO_2 emissions, weak environmental controls, large population growth and regionally oriented economic development. It represents a high-end estimate of future relative sea-level rise.[112]

Sea level rise for Connecticut could range between 4 and 8 inches above the mean of the 1961–1990 values by the 2020s, climbing to 7–17 inches by the 2050s, and up to 9–35 inches by the 2080s (Figure 10). These forecasts fall toward the high end of the recent projections of the Intergovernmental Panel on Climate Change.[113] Future Connecticut sea-level rise is expected to be greater than the global trends, due to the regional subsidence discussed above.

Impacts of coastal storms and sea level rise on urban areas

HISTORIC STORMS AND FUTURE TRENDS

Coastal storms affecting Connecticut are of two types: nor'easters and hurricanes.

Nor'easters are the most common type of coastal storm affecting Connecticut. Although wind speeds and surges are lower than for hurricanes, they can still inflict considerable damage because they extend over a much broader area and last over several tidal cycles. They are most prevalent between December and March. There has been no statistically significant increase in the number or severity of storm-surge events along the East Coast in the last 50 years.[114] Any apparent increase in flooding is largely a consequence of regional sea-level rise, coastal erosion and extensive coastal development.

Of recent nor'easters that have hit Connecticut, severe storms include the Halloween storm (October 31–November 1, 1991, as immortalized in Sebastian Junger's book, *The Perfect Storm,* and a powerful coastal storm, December 11–12, 1992. In Connecticut, the Halloween storm generated tides five feet above normal, with wind gusts over 60 miles per hour.[115] Milford was among the hardest-hit communities, with floodwaters 10 to 12 feet above normal. The December 1992 nor'easter also caused major coastal flooding and power outages and disrupted transportation.[116]

Several recent studies indicate that although there has been no increase in nor'easter activity along the East Coast, there has been some increase in non-tropical storms in the Northern Hemisphere during the second half of the 20th century overall.[117] However, it is not clear to what extent these observations reflect large-scale inter-decadal atmospheric fluctuations, such as the North Atlantic Oscillation (NAO) or the Arctic Oscillation, or are part of a longer-term trend related to the observed warming. Climate models have not yet provided a consistent, reliable picture of future behavior.

Hurricanes are major tropical cyclones or low-pressure systems that develop over oceans warmer than 78.8°F. Their destructiveness derives from very high wind speeds (at least 74 mph), heavy rainfall and flooding due to the high storm surge. The surge is a dome of high water created by the low atmospheric pressure and strong winds, particularly on the right side of the cyclone. The height of the surge at landfall also depends on the strength of the storm, the storm track and phase within the tidal cycle. Waves can also contribute to the surge height.

While hurricanes are less frequent than nor'easters in Connecticut, they have been responsible for some major disasters. The east-west oriented Connecticut coastline lies in the path of northward-moving tropical cyclones. At least eight hurricanes have struck Connecticut within the last 100 years, including major ones in 1938, 1944 and 1954 (Table 6).[118] The worst natural disaster in the northeastern U.S. was the hurricane of September 21, 1938, which killed over 600 people and injured thousands.[119] This storm had winds of 115 mph and a storm surge up to 25–35 feet. The magnitude of the storm, combined with little advanced warning, resulted in damages estimated to be over $4.7 billion (adjusted to 2000 dollars).[120] The storm also eroded protective barrier dunes and buildings on the shores of Long Island, Connecticut and Rhode Island, adding to its cost. The cost of a similar storm today would be much higher because of the extensive development of Long Island and the Connecticut shoreline.

Connecticut has seen several other destructive hurricanes in the past 50 years. Hurricane Carol in 1954 was extremely destructive, with winds of 115–125 miles per hour and 8–10 foot surges. It caused 65 deaths and $3.1 billion in damages.[121] Two hurricanes (Connie and Diane) struck Connecticut in mid-August of 1955.

TABLE 6
Major hurricanes affecting Connecticut in the 20th century

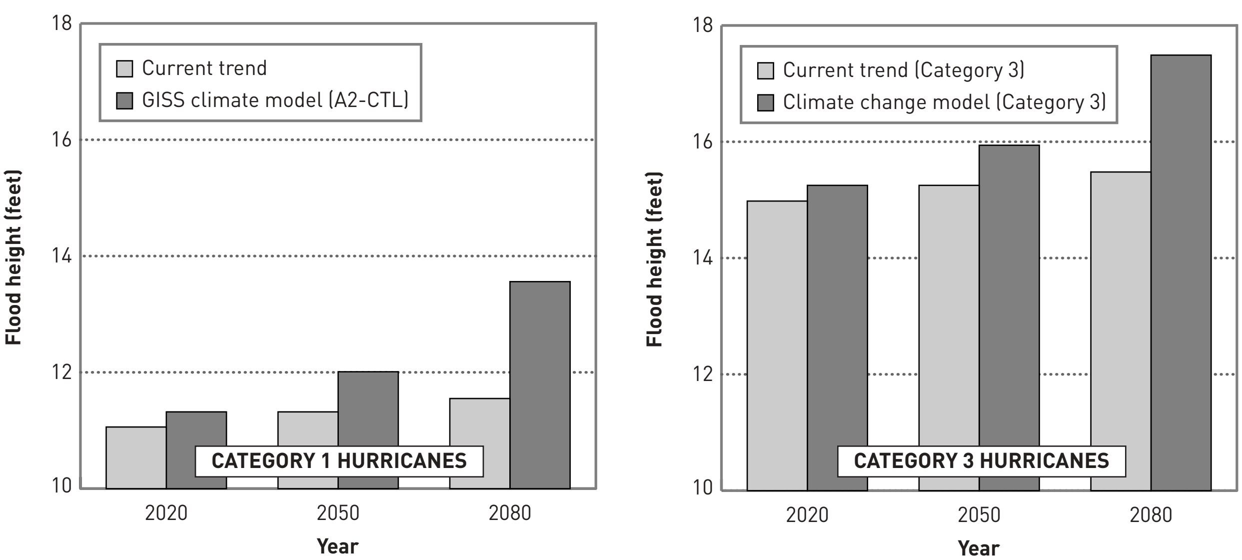
Name	Year	Category	Sustained winds mph	Comments
	1938	3	115	Killed 85 people in CT alone. Hit at high tide; surges 12-16 ft (3.6–4.8m).
	1944	3	~90	
Carol	1954	3	100	Killed 65 people. Hit at high tide, surges ~8–13ft (2.4–3.9m).
Connie	1955	1	72-83	Severe inland flooding.
Diane	1955	2	72-83	Severe inland flooding.
Donna	1960	3-4	95	Major coastal damage.
Belle	1976			Heavy rains.
Gloria	1985	3	85	Hit at low tide. Minor coastal flooding.

Source: Coch, N.K., 1994. Hurricane hazards on the northeast Atlantic Coast of the United States. *J. Coast. Res. Spec. Issue No. 12,* 115–147. Jarrell, J.D., Mayfield, M., Rappaport, E.N., and C.W. Landsea. 2001. The Deadliest, costliest, and most intense United States hurricanes from 1900–2000 (and other frequently requested hurricane facts). NOAA Tec. Memo NWS TPC-1.

While the storm surges were minor, the extremely heavy rainfall produced some of the worst inland floods in the state's history. Hurricane Gloria (1985) recorded winds of 85 miles per hour by the time it reached Connecticut. Fortunately, Gloria's 7-foot storm surge arrived at low tide and its effects were lessened, demonstrating the dependence of flood damage on the tidal cycle. Both the 1938 and 1954 hurricanes struck at high tide, producing severe coastal flooding.

It is unclear what effect global warming will have on the frequency and intensity of hurricanes. Hurricanes form over warm water, so global warming could increase the

FIGURE 11
Projected range of flood levels for Category 1 and 3 hurricanes in Bridgeport, CT



amount of ocean area favorable to hurricane formation. However, it is possible that other variables may counteract these increases. Hurricanes display considerable inter-decadal variability, and so far no significant long-term trends have emerged.

PROJECTED FLOOD LEVELS

Assuming that future hurricane characteristics will remain similar, we estimate changes in coastal flooding associated with future sea-level rise. Figure 11 shows flood heights for hypothetical Category 1 and 3 hurricanes for Bridgeport. Data for other locations along the Connecticut coast is provided in Table 7. Flood height is calculated as the sum of the storm surge (based on the National Hurricane Center's Sea, Lake and Overland Surges from Hurricanes (SLOSH) model),[122] sea level rise (Figure 10), and the difference between mean high water and mean tide level (assuming that the storm hits at high tide). This worst-case scenario also assumes that the storm track passes slightly to the west of New York City, producing the highest surges over western Long Island and Connecticut. Waves (not included here) could add to the total flood height.

TABLE 7

Projected flood heights (ft) for various locations along the Connecticut coast for Category 1 and 3 hurricanes

Flood heights are obtained using the SLOSH model surge output, combined with sea level and tide level. In addition we assumed that the storm struck at high tide. Surge level taken from the Metro New York Hurricane Transportation Study.

CURRENT TRENDS SCENARIO

	2020s Flood heights (ft)		**2050s Flood heights (ft)**		**2080s Flood heights (ft)**	
Location	**Cat. 1**	**Cat. 3**	**Cat. 1**	**Cat. 3**	**Cat. 1**	**Cat. 3**
Greenwich Cove	12.53	15.22	12.80	15.49	13.02	15.72
Shippan Point	12.14	14.63	12.40	14.90	12.63	15.12
Stamford	12.04	14.24	12.30	14.50	12.53	14.73
Norwalk	11.06	13.98	11.32	14.24	11.55	14.47
Westport	10.83	13.94	11.09	14.21	11.32	14.44
Bridgeport	10.99	14.90	11.25	15.16	11.48	15.39
Stratford	11.32	15.32	11.58	15.58	11.81	15.81

GISS CLIMATE MODEL SCENARIO (A2-CTL)

	2020s Flood heights (ft)		**2050s Flood heights (ft)**		**2080s Flood heights (ft)**	
Location	**Cat. 1**	**Cat. 3**	**Cat. 1**	**Cat. 3**	**Cat. 1**	**Cat. 3**
Greenwich Cove	12.80	15.49	13.48	16.17	15.03	17.72
Shippan Point	12.40	14.90	13.09	15.58	14.63	17.13
Stamford	12.30	14.50	12.99	15.19	14.53	16.73
Norwalk	11.32	14.17	12.01	14.93	13.55	16.47
Westport	11.09	14.21	11.78	14.90	13.32	16.44
Bridgeport	11.25	15.16	11.94	15.85	13.48	17.39
Stratford	11.58	15.58	12.27	16.27	13.81	17.81

Source: U.S. Army Corps of Engineers/Federal Emergency Managment Agency/ National Weather Service, Metro New York Hurricane Transportation Study,Interim Technical Data Report, 1995) and tidal ranges are taken from NOAA/NOS/Co-Ops: National Oceanic and Atmospheric Administration, National Ocean Service, Center for Operational Oceanic Products and Services, http://140.90.78.170/).

By extrapolating current sea level trends, we project that flood heights for all locations studied could range from 11.5 to 13 feet for a Category 1 hurricane, and 14.5 to 15.7 feet for a Category 3 storm by the 2080s. The GISS Climate Model scenario projects flood heights between 13.5 and 15.1 feet for a Category 1 hurricane, and 16.4 and 17.7 feet for Category 3 (Table 7) by the 2080s. By the 2080s, rising sea level could account for 18-22% of the increase in flood height in the high sea-level rise scenario and 6-8% in the low case.

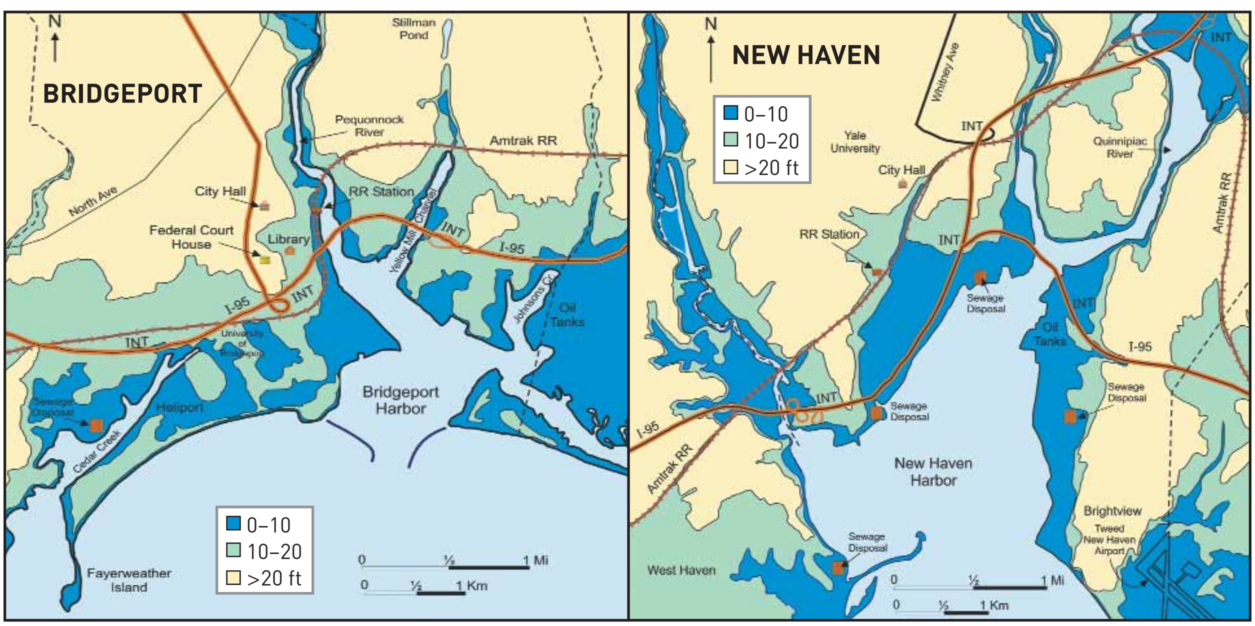
Category 3 hurricanes that produced floods above 11.5-13 feet have struck Connecticut twice in the past century, in 1938 and 1944. With rising sea level, floods generated by storms of this magnitude could approach 18 feet by the 2080s (see Table 7). In other words, Category 1 or 2 hurricanes could attain the flood potential of today's Category 3 storm. Since Category 1 or 2 hurricanes are more likely than Category 3 storms, more frequent severe coastal flood events can be anticipated.

IMPACTS OF SEA LEVEL RISE AND FLOODING IN BRIDGEPORT AND NEW HAVEN

Vulnerability to sea-level rise and storms is assessed qualitatively (see Figure 12), by overlaying topographic information with projected sea levels and flood heights. A significant portion of both Bridgeport and New Haven lies within the high-risk flood zone, placing a large population, considerable private property and infrastructure at risk during severe storms. Important infrastructure at risk includes the New Haven railroad station and track yards, the Tweed-New Haven Airport, a number of ramps to the Connecticut Turnpike (I-95), approaches to bridges, several New Haven and Brightview sewage disposal plants and the Brightview oil storage tanks. In Bridgeport, vulnerable structures include portions of the Amtrak railroad, entrances to Connecticut Turnpike interchanges and bridges, the Univer-

FIGURE 12

Areas potentially at risk to coastal flooding by hurricanes



By the 2080s, projected flood levels for Connecticut coastal cities during Category 3 hurricanes could range between 14.5 and 18 feet.

sity of Bridgeport, the Navy Reserve Center, the Heliport, sewage disposal plants and the oil tanks at Johnson Creek.

Effects of sea-level rise on coastal wetlands and marshes

CONNECTICUT'S TIDAL MARSHES

Salt marsh formation in Connecticut has been facilitated by a combination of favorable geological and climatological factors. The region's post-glacial sea level rise has created a "drowned" coastline, marked by numerous estuaries, coves, headlands and streams. The retreating glaciers left behind ridges of gravel, boulders and clay known as moraines. Moraines such as Long Island, Plum Island and Fisher's Island act as a "huge natural breakwater,"[123] protecting the Connecticut shoreline from the brunt of storm-generated waves. The orientation of Long Island and the narrowness of Long Island Sound also act as barriers, limiting the height of waves breaking on the Connecticut coast. Three major rivers, the Connecticut, Thames and Housatonic, deposit sediments on the Connecticut coast as they drain into the Long Island Sound. These factors combine to create an ideal location for coastal wetlands known as salt marshes.[124] Wetlands are important because they serve as nurseries for fish and other animals, shelter migrating birds and help to filter pollution from drinking water.

Salt marshes in Connecticut have been vastly modified by human activities. Since colonial times, humans have been ditching and draining salt marshes for coastal development, to harvest marsh grasses and hays, and for mosquito control. By the 1940s, nearly all of Connecticut's salt marshes had been ditched.[125]

The Tidal Wetlands Act, passed in 1969, required that permits be obtained from the Connecticut Department of Environmental Protection to build on tidal wetlands. This law, in addition to environmentally sound open-marsh-water management, has resulted in substantial wetland protection within the state. However, despite these improved practices, urban development has resulted in the loss of between 30% and 50% of Connecticut's tidal wetlands between the 1880s and 1970s.[126]

WETLANDS AND SEA-LEVEL RISE

Although human activities have been the major historical cause of Connecticut's wetland loss, future sea-level rise will play an increasing role in the loss of coastal wetlands . Coastal wetlands require a delicate balance between sea level, sedimentation rate and erosion.[127] In response to past sea-level rise, wetlands have typically increased sediment deposition and migrated landward. However, rapid coastal development has made landward migration increasingly difficult. In several parts of the United States, rates of relative sea-level rise already exceed rates of accretion and compaction. As a result, marshes are beginning to disappear. This has already occurred in Louisiana,[128] in the Chesapeake and Delaware Bays[129] and in parts of southern Long Island.[130] The island salt marshes at the Gateway National Recreation Area in Jamaica Bay, New York, have declined by 50% since the 1920s, with losses accelerating in recent decades.[131] The extent of these losses may be unusual because of the long history of human intervention in Jamaica Bay. Yet the fate of these marshes may serve as a wake-up call for other coastal wetlands facing the intertwined hazards of sea level rise and human-induced stresses.

Using a simple model, we assessed the role of sea-level rise on Connecticut's tidal wetlands for the 2020s, 2050s and 2080s. The simple model assumes that marsh

TABLE 8

Difference between accretion and sea-level rise (inches) for tidal wetlands, assuming low, medium, and high accretion rates

Changes in sea level are relative to the decadal mean of the 2000s. Negative numbers (bold) indicate where sea level rise exceeds accretion.

Decade	2020s			2050s			2080s		
Accretion rate	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
SCENARIO									
Current trends									
Bridgeport	**–0.5**	1.9	4.2	**–1.1**	4.7	10.6	**–1.8**	7.6	16.9
New London	**–0.1**	2.2	4.6	**–0.3**	5.6	11.5	**–0.4**	9.0	18.3
GISS climate model (A2-CTL)									
Bridgeport	**–4.2**	**–1.8**	0.5	**–10.1**	**–4.3**	1.6	**–26.1**	**–16.7**	**–7.4**
New London	**–4.2**	**–1.9**	0.5	**–10.2**	**–4.3**	1.5	**–26.2**	**–16.9**	**–7.5**

elevation changes correspond to changes in accretion rates, but neglects subsurface compaction.[132] A range of plausible accretion rates is used, based on a review of published values: the low value (L) = 0.08 inches per year; medium (M) = 0.20 inches per year; and high (H) = 0.31 inches per year[133] (Table 8). Negative numbers indicate that sea-level rise exceeds accretion. Our results suggest that salt marshes with moderate-to-high accretion rates would generally be able to keep pace with current rates of sea-level rise throughout this century. However, with the projected increased rates of sea-level rise, only marshes with high accretion rates could survive through mid-century, and even they would be completely submerged by the 2080s.

Adapting to sea-level rise

Strategies for coping with rising sea levels include defending the shoreline with "hard" structures, such as seawalls, groins, jetties and breakwaters. As sea level rises, existing structures will need to be strengthened and elevated repeatedly. Retrofitting structures or armoring selected portions of the coast is extremely expensive and may be viable only in high population or high property-value areas. Recent studies indicate that planning ahead can reduce the costs associated with adapting to climate changes.[134]

Because of erosion problems associated with hard structures, dune restoration and beach "renourishment" have become the preferred means of shoreline protection.[135] This "soft" approach consists of placing sand that has usually been dredged from offshore or other locations onto the upper part of the beach. However, as a result of worsening erosion caused by higher sea levels, sand replenishment will need to be applied more frequently.

Sea-level rise caused by climate change will increase the costs of both "hard" and "soft" protection measures. Debates have already arisen about whether taxpayer money from inland communities should be used to support such programs, from which these communities benefit only indirectly, if at all.

As a last resort, retreat from the shore may become an appropriate option, especially in areas of lower population densities, or in high-risk areas subject to repeated storm damage. The retreat could be gradual, or sudden, following a catastrophic storm. Possible retreat mechanisms could include: establishing setback lines based on projected sea-level rise; removing structures that are in imminent danger of collapse into the sea; ending the subsidized rebuilding of structures in designated hazard zones; and prohibiting structures that would interfere with natural shoreline migration.[136] Each of these strategies will require the cooperation of diverse interest groups and government agencies. Climate change, even with a successful mitigation program, will result in visible changes to the Connecticut coastline.

FLOOD AND STORM PREPAREDNESS

A number of local, state, federal and private agencies are involved in disaster management and relief. These include the Connecticut Department of Environmental Protection, the Connecticut Office of Emergency Management, the National Weather Service, the Federal Emergency Management Agency, the U.S. Army Corps of Engineers and the American Red Cross.

The National Weather Service (NWS) routinely tracks storms and hurricanes using satellite imaging and other methods. Though forecasting methods have greatly improved over the last decade, accurate predictions of hurricane and storm tracks cannot be made more than half a day in advance. Given the large uncertainty in tracking these storms and the large urban population potentially at risk, evacuation plans must encompass large areas and people must be prepared to evacuate on relatively short notice.

When storms occur, the NWS works closely with the Connecticut Office of Emergency Management to assess the situation at a local level.[137] Storm-surge levels are estimated using the SLOSH model.[138] If major damage is anticipated, the NWS announces a coastal flood watch to warn of possible flooding or a coastal flood warning, which indicates likely flooding. Since the NWS focuses on short-term weather prediction, they have no specific preparations for climate change.

The Federal Emergency Management Agency (FEMA) provides monetary assistance for natural disaster recovery. FEMA also manages the National Flood Insurance Program (NFIP), designed to assist communities affected by flood damage. NFIP provides flood insurance to communities that adopt measures to reduce future flood risks in hazardous areas.[139] NFIP also calls for designating erosion zones and setbacks or buffer zones for highly vulnerable coastal areas.

The U.S. Army Corps of Engineers is responsible for building and managing dams and levees to minimize flood damage. They also are involved in beach "renourishment" and some tidal marsh restoration programs. In Connecticut, the Army Corps has constructed hurricane barriers in New London, Pawcatuck and Stamford that have effectively minimized flood damage. However, flooding has not reached levels of historic highs since the construction of the barriers.[140] The Army Corps usually incorporates current sea-level trends into their calculations, but so far has not taken into account the role of future climate change.

The Connecticut Department of Environmental Protection, Office of Water Management helps communities prepare hazard-reduction plans and runs workshops on NFIP. Sea level rise is informally considered, but at present no specific plans exist to deal with future flooding.[141]

The Connecticut Office of Emergency Management (OEM) organizes evacuations and helps implement recovery programs for coastal flooding. The agency also works to obtain state or federal funding as needed.[142] On the regional level, OEM coordinates storm-preparation plans with coastal communities, updating

The Long Island Sound lobster die-off: A sign of things to come?

Lobsters have been a part of Jim King's life for over 50 years. Jim's father was a fisherman in the Long Island Sound starting in the 1940s, and Jim has been a lobsterman himself for more than 40 years. He has a real appreciation for the mysteries and charms of lobsters: "Every time you think you know something about them, they do something unexpected. They're very unique animals."

Jim has seen good years and bad years since he started trapping lobsters almost half a century ago. From the mid-1970s to the mid-1990s, lobster populations rose steadily, despite some minor die-offs in the early 1990s. But starting in 1999 lobsters in the Long Island Sound began dying in record numbers. In some parts of the Sound, virtually 100% of the lobsters died. By 2003, lobster populations were down 70% from 1998 levels.[145] It was more than just a bad year.

The economic impacts of the die-off have been devastating. In 1998, at the peak of the lobster catch in the Sound, New York and Connecticut landings totaled $42 million, about 15% of the total value of U.S. lobster landings that year.[146] In Connecticut, about $12 million in total dockside value was generated from lobsters. By 2002, the total value of the Long Island Sound lobster industry had plummeted to $10 million, with about $4 million generated in Connecticut. Commercial lobster licenses fell by almost 50% from the mid-1990s to 2002, and many of those who were granted licenses did not even find it worthwhile to put out traps. [147]

Trapping on the eastern part of the Sound, which was less affected, spared lobsterman Jim King most of the economic misfortune. However, he remembers the horror stories of his fellow lobstermen pulling up traps full of dead lobsters and crabs. Though Jim has been able to pull through the hard times, many lobstermen in Long Island Sound have been plunged into financial ruin.

In 2000 the U.S. Secretary of Commerce declared the area a "resource disaster." Over $7 million dollars was allocated to assist the affected lobstermen. In addition, over $7.5 million dollars in federal funds went to finance the Long Island Sound Lobster Research Initiative, a state and federal effort to determine the causes of the die-off.[148]

Scientists discovered that lobsters in the Sound have experienced unprecedented levels of disease in recent years. Diseases affecting the lobsters include parasite infections, a bacterial infection known as shell disease and calcinosis, a disease similar to kidney stones in humans.

A number of factors could have contributed to making the lobsters more susceptible to diseases. Many scientists have agreed that warmer water temperatures, most likely due to climate change, contributed to the die-off. But other factors most likely played a role as well, such low oxygen content in the bottom waters (hypoxia) and pesticide runoff.[149]

INCREASED WATER TEMPERATURES

Lobsters are poikilothermic or "cold-blooded," which means their body temperature is determined by the temperature of the water they live in. Lobsters can tolerate a broad range of temperatures, living in waters that range from below 32°F in winter to as high as 77°F in the summer. However, laboratory studies show that temperatures above about 77–86°F are lethal.[150] Coastal bottom waters off the Long Island Sound fall within the uppermost limit of the lobsters' tolerance range, reaching an average of about 22°C during the summer months.[151]

In the Long Island Sound, water temperatures are determined by the overlying air mass. This is because the water is shallow and doesn't mix much with the deep Atlantic Ocean water, especially in the western Sound. Therefore, if air temperatures are high, temperatures in the bottom waters, where lobsters live, can become quite warm.

The air temperatures in the summers of 1999 and 2002 were the fourth and fifth hottest in 108 years of record keeping in Connecticut. The trends were similar in New York City, which in 1999 experienced the highest recorded summer temperatures, followed by the summer of 2002.[152] Measurements show that the Sound also was unusually warm in these years. The high temperatures placed an enormous amount of stress on the lobsters, which most likely played a role in making them more susceptible to disease. In fact, calcinosis, which lobsters in the Sound began experiencing in 2002, is a metabolic disease scientists think is directly related to high water temperatures.

Scientists predict that global average temperature could rise by 4–10°F in the next hundred years due to global warming.[153] The change in air temperature for the Long Island Sound area would also fall in this range, and water temperatures are likely to rise as a result, creating the possibility that lobsters will no longer be able to survive there.[154]

OTHER FACTORS THREATENING LOBSTERS

Higher water temperatures are not the only factor threatening lobster populations in the Sound. However, the other factors, such as increased predators, low oxygen in bottom waters and pesticide runoff could be exacerbated by climate change.

Increased predators. Lobster predators, including striped bass, summer flounder and tautog, are at record high levels.[155] These predators are all mid-Atlantic species that do well at higher water temperatures. The same increase in water temperatures that has weakened lobster populations is also causing the predator population to flourish.

Low-oxygen content (hypoxia). Hypoxia occurs when there is low dissolved oxygen content in bottom waters. Lobsters need oxygen to survive, so hypoxia can be a major stress on their immune systems. Hypoxia results when there is a high influx of nutrients, especially nitrogen, into the water. In the Long Island Sound, sources of nitrogen include sewage and industrial waste and fertilizer runoff from farms and yards.[156] The nitrogen causes outbreaks of algae that consume large amounts of oxygen. High water temperatures also exacerbate hypoxia, which is believed to be a chronic problem in the Long Island Sound and was recorded in 1999 during the die-off.[157]

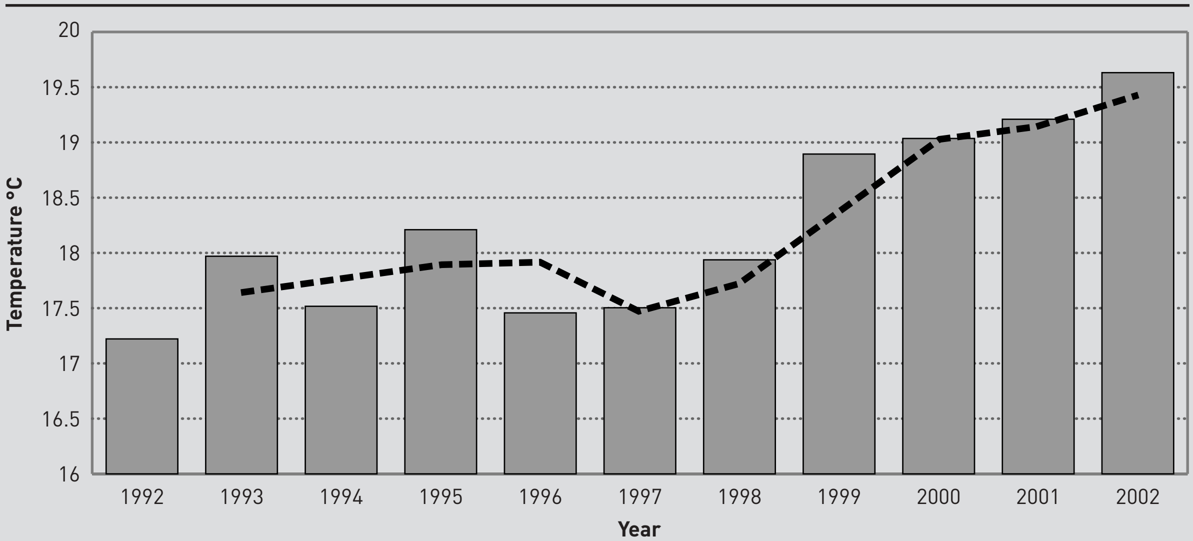
Pesticides. Beginning in the summer of 1999, New York and Connecticut have experienced outbreaks of the West Nile virus, which may be spreading because of changes in climate. To kill the infected mosquitoes, spraying of the pesticides malathion and methoprene has increased. Scientists fear the pesticides may affect lobsters. Research has shown that malathion inhibits the lobster's immune system at low doses.[158] Exposure to methoprene, which works by mimicking a hormone in insects that regulates growth, molting and reproduction, may stimulate molting in lobsters at inappropriate times.[159] However, given that the lobster's mortality has spread to southern Massachusetts and that the majority of the deaths have occurred in late summer, it is unlikely that pesticides are the only factor influencing the lobster die-off.

THE FUTURE OF THE LOBSTER INDUSTRY IN THE LONG ISLAND SOUND

It will take at least several years for the lobster populations in the Long Island Sound and southern New England to rebound. However, the industry's long-term survival depends on reducing environmental stressors. In addition to limiting polluted runoff and avoiding the use of toxic pesticides, it will be especially important to curb the greenhouse gases that cause global warming. This will help ensure that the water temperatures remain at a suitable level for lobsters to thrive so that lobstermen like Jim King can carry on the tradition of lobster fishing in the Long Island Sound for generations to come.

FIGURE 13

Long Island Sound bottom water temperature, July–October, 1991–2002



Source: CTDEP Water Bureau

plans every four years. Flood-response efforts include elevating private homes and mapping "special needs places" such as nursing homes and hospitals to facilitate evacuation. The agency has no plans at present to deal with sea-level rise.[143]

The American Red Cross, South Central Connecticut Chapter, works closely with state, local and federal agencies, especially the Connecticut Office of Emergency Management. It provides temporary shelter for evacuees and financial assistance to disaster victims. Although it has no specific plans to deal with climate change impacts, the Red Cross has greatly improved its preparations for all types of disasters and their communications infrastructure since 9/11.[144]

While the services provided by these agencies are more-or-less adequate to cope with disasters based on historic experience, little thought has been given to preparations for impacts associated with sea-level rise. Sea-level rise is likely to be relatively small in the next 20 years compared to the second half of this century, so the coming decades should be spent developing mitigation and adaptation strategies.

Conclusion

Climate change poses clear threats to Connecticut. Scientific consensus affirms that past emissions of greenhouse gases will lead to warmer temperatures and rising sea levels, affecting the health of residents and the state's economy. It is our responsibility to act now to limit these impacts and protect our homes and families.

Some initial steps have been taken to address greenhouse gas emissions. At the federal level, Connecticut Senator Joseph Lieberman and Arizona Senator John McCain have introduced the Climate Stewardship Act, a cost-effective measure to limit greenhouse gases in all parts of the economy nationwide. Though the Senate rejected the bill in 2003 in a close vote, 43 senators supported the measure, marking a political turning point in the climate change debate, and proving that there is growing demand for action.

At the regional level, Connecticut has committed to work with other Northeast states to address climate change. In 2001 the New England governors and Canadian premiers adopted the Climate Change Action Plan to reduce emissions. The Action Plan includes goals to reduce regional greenhouse gas pollution to 1990 levels by 2010 and to at least 10% below 1990 levels by 2020. In addition, 10 New England governors joined New York Governor Pataki this summer in agreeing to develop a regional strategy to reduce carbon dioxide emissions from power plants using a market-based emissions trading system to bring down costs. Connecticut has already begun to establish a framework for meeting the goals embodied in the Climate Change Action Plan. The Connecticut Climate Change Stakeholder Dialogue, including representatives from Connecticut businesses, non-governmental organizations, and state agencies, recently issued its January 2004 Concluding Report (available at www.ccap.org) identifying over fifty policies that could be put in place as a means to achieve these goals.

The time is now ripe for Connecticut to establish a timetable for moving forward expeditiously to evaluate and implement the recommendations in the report. An obvious place to start is the transportation sector, which contributes 39% of Connecticut's greenhouse gas emissions—more than any other sector. Connecticut can take the lead where national action is lacking and adopt California's strict vehicle emissions standards, including those to address greenhouse gases, a step Massachusetts, New York, and New Jersey have already taken. By shifting to less-polluting energy sources and more efficient vehicles, Connecticut will not only reduce greenhouse gas emissions, but will also reduce its dependence on oil and improve air quality in the state.

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