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Climate Change, Regional Impacts and Adaptation

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Climate change policy must be based on sound science. It is incumbent upon those of us in the research community to identify what we know about climate change, how well we know it, and what we don't know, and clearly articulate that information for policy makers and the general public.

The focus of this presentation is on two questions:

1. How well do we understand the climate system and our role in influencing it?
2. How well can we characterize the potential impacts of climate change?

The Greenhouse Effect

There is a natural greenhouse effect and it's principles are very well understood. On a relative scale of one to 10, where 10 represents highest confidence and one represents lowest confidence, we attach a confidence level of 10 to this concept. Basic physics tells us that when an object like the Earth is bathed in visible light, it warms and emits infrared radiation. There are particular gases in the atmosphere called greenhouse gases (*e.g.*, water vapor, carbon dioxide [CO_2], nitrous oxide and methane) that reabsorb and re-emit some of this radiation. In some sense, they "trap" heat in the Earth's atmosphere and warm the

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globe. Average global temperatures are approximately 60°F as a result of this “greenhouse effect,” which sustains human life. In the absence of the greenhouse effect, the average global temperature would be about 5°F.

What is remarkable about the greenhouse effect is that greenhouse gases represent a very small component of the atmosphere. For example, water vapor is only about 2% of the atmosphere, and CO_2 is about .03%. Yet, these gases result in a warming effect that makes the planet habitable.

This natural greenhouse effect is good. So what's the problem? The problem is that greenhouse gases are increasing in the atmosphere because of human activities, enhancing the greenhouse effect and increasingly trapping more heat. The rate of increase of greenhouse gas concentrations in the atmosphere since the Industrial Revolution has been dramatic. If one compares concentrations in 1994 to pre-Industrial levels, one finds that CO_2 has risen about 30%, methane over 100%, and nitrous oxides about 15%. Our confidence in these numbers is high (*i.e.,* a confidence level of 10). They come from impeccable scientific measurements.

Some of these gases have very long atmospheric lifetimes. For example, CO_2 has a residency in the atmosphere of anywhere from 50 to 200 years. This fact, combined with the inertia in the climate system (*e.g.,* the lag with which oceans respond), means that any warming that occurs as a result of human activities can only be reversed very slowly.

Sources of the Problem

Who is responsible for this problem? What human activities are contributing to the problem? The answer is that we are all part of the problem. First consider the U.S. In 1994, the total greenhouse budget for the U.S. was 1.6 billion metric tonnes of carbon equivalent. The U.S. is responsible for 20% of global carbon emissions, despite the fact that it represents under 5% of the total global population. The U.S. is a big contributor to the problem.

Within the U.S., the largest share of the total carbon budget is accounted for by emissions of CO_2, which come primarily from fossil fuel combustion. These CO_2 emissions come from millions of diverse sources throughout the economy. They come from the transportation, industrial, commercial, residential, and utility sectors of the economy.

Unlike other environmental problems, no single sector of the U.S. economy is solely responsible for CO_2 emissions.

Next consider the international picture. The U.S. and other OECD countries, including Canada, have been and currently still are major emitters of greenhouse gases. However, projections of global greenhouse gas emissions out to the year 2025 suggest that total emissions will continue to rise and an increasing share will come from the developing countries. In order for us to have any influence on the climate system in the long run, the developing countries also have to be part of the solution. We are all part of the problem.

Potential Consequences for the Atmosphere

What are the potential consequences of this human influence? As illustrated in Figure 1, atmospheric concentrations of CO_2 prior to the Industrial Revolution were roughly 280 parts per million by volume (ppmv). Since the Industrial Revolution, CO_2 concentrations have been rising and now stand at around 360 ppmv. If left unabated, atmospheric concentrations of CO_2 are expected to double relative to pre-Industrial levels by the year 2060 and reach 560 ppmv (the so-called "2xCO_2 world"). By the year 2100, CO_2 concentrations will double relative to current levels and reach about 720 ppmv (confidence level of 7).

Let's put these projected changes into the context of a long historical record. Figure 2 illustrates the Antarctic ice core record for the last 160,000 years. Two things emerge from this record. The first is that there is a close correlation between atmospheric concentrations of carbon dioxide and global temperatures. Second, even though there have been large fluctuations in CO_2 concentrations in the past, they have never reached the 720 ppmv level that is expected by 2100. Of particular concern is the rate at which CO_2 concentrations are expected to increase. We are talking about changes beyond human experience.

Are surprises possible? Are abrupt climate shifts possible? Yes. We are entering a new region of climate perturbation that we have never been in before. The climate system, which is a non-linear system, may respond in unexpected ways.

Potential Consequences for Climate

What are the consequences of human activities for the climate system? A continued future growth in greenhouse gases is predicted to lead to significant climatic changes. The Intergovernmental Panel on Climate Change (IPCC) concluded in its 1995 Second Assessment that average global temperature will increase 1.8°F to 6.3°F by the year 2100, with a "best estimate" of 3.6°F. But climate change is more than temperature change. Sea level will also rise. Average global sea level is expected to rise between 6 and 38 inches by 2100, with a best estimate of 20 inches. Precipitation is also going to be affected. The hydrologic cycle will intensify and it will likely become a wetter world. The intensity with which rainfall and snowfall occur may change, and floods and droughts may become more frequent. These are changes that are greater than anything we have seen in the last 10,000 years, and all of these anticipated changes have important implications for impacts and adaptation.

Is the Climate Already Changing?

Is this all pie in the sky? Have we seen any evidence of climate change, whether or not it's human-induced? Yes. The climate has changed and it will continue to change. Average global temperature during the last hundred years has risen 0.5°F - 1°F. Average global sea level has risen 4 to 10 inches, and precipitation has gone up approximately 1%. It has, on average, become a hotter and wetter world.

The IPCC concluded that some of this change in climate can be attributed to human activities and stated "that the balance of evidence suggests a discernible human influence on global climate." It is not yet possible to identify what fraction of observed climate change was human induced. But a human fingerprint has been detected in the climate record (with a confidence level of 5).

Regional Texture of Changes

Up until now we have been talking about global averages. This conference is about the Great Lakes, so let's talk about regional impacts. Figure 3 depicts the temperature and precipitation records over the last 100 years for the United States. With the exception of the Southeast, it has generally become warmer in the United States. However, there is a regional texture to the changes. The warming is not uniform across the country. The increases have ranged from 1°C to 3°C, depending upon location.

We suspect that the cooling in the Southeast may be the result of increased industrialization and economic growth which led to increased emissions of sulfur dioxide which is transformed into sulfate aerosols. These aerosols increase the Earth’s albedo and have a regional cooling effect. In a sense it masks the warming that is occurring.

There is also a regional texture to the precipitation record, with increases ranging from 5% to 20%, and decreases elsewhere. What's going on in New Jersey is very different than what's going on in California.

The character of rainfall has also changed. Figure 4 depicts the character of the precipitation changes that have occurred since 1900. It shows that the area of the U.S. that was affected by more extreme rainfall events (*i.e.,* at least two inches per day) has gone up. This is of concern to anyone interested in the potential impacts of climate change and climate variability -- whether it’s to agriculture, forestry, urban water supplies or hydropower -- where one needs to worry about the rate at which precipitation events occur.

The key message is that there is a regional texture to climate change.

Potential Impacts

How well can we characterize the potential impacts of climate change? What does climate change mean for the average individual today and in the future?

Human health, natural ecological systems, and socioeconomic systems are all sensitive to both the magnitude and the rate of climate change. However, making predictions about impacts is difficult. Our understanding of the climate system is the best at larger geographic scales, yet impacts occur regionally and locally. Our ability to translate predictions of large scale changes in future climate into regional and local changes is limited. Despite this limitation, many valuable insights have been obtained about the risks to human health, the environment, and the economy, including:

1. Many systems that are vulnerable to climate change have already been identified (Figure 5). These include human health, agriculture, forests, water resources, coastal zones, and biodiversity.

2. In the same way that there is a regional texture to climate change and climate variability, there will be a regional texture to the impacts of climate change on human health, ecosystems, and economic systems. If one is assessing the potential impacts of climate change, one must focus on a regional scale. It can be very misleading to only focus on impacts at an aggregate national level.

3. Many of the systems vulnerable to climate change and climate variability are already under stress from other factors. Climate change is an additional stressor on these systems.

4. The impacts from climate change to various systems will occur simultaneously. The systemic nature of climate change poses unique challenges to resource managers.

5. The ability of natural ecological systems to migrate appears much slower than the predicted rate of climate change. For example, the inability of forests to migrate as quickly as the predicted rate of climate change may lead to changes in the composition and distribution of forests across the United States and Canada.

6. There are going to be winners and losers. If you look at any one potential impact category, some regions may benefit (at least in a $2xCO_2$ world) and others will be harmed. However, when you look across all impact categories, every region will experience some negative impacts from climate change.

7. The climate system is a dynamic system. The climate is already changing and impacts may already be occurring. Many people have the mistaken impression that there won't be any impacts until we reach a $2xCO_2$ world, and then there will suddenly be dramatic changes in the climate. That's not the way the real world works. The climate is already changing and some incremental impacts of climate change may already be occurring.

These insights can be illustrated with a few specific examples of potential impacts to human health, coastal zones (as a result of sea level rise), water resources, and agriculture:

Human Health

Climate change will affect human health through various pathways, some more direct than others. Some of the more direct effects include heat stress and health effects due to changes in extreme weather events such as floods. Some of the more indirect effects include the potential spread of infectious diseases, and impacts on health from changes in air quality and sea level rise.

Climate change is expected to increase the frequency of very hot days during the summer. Therefore, the number of deaths due to heat stress may rise. Figure 6 depicts increases in average annual weather-related mortality due to climate change for selected U.S. cities under one climate scenario. Note the regional texture to these impacts. The impacts of climate change on human mortality is city specific. This is due to a number of factors, such as differences in infrastructure, the extent to which people have physiologically adapted to extreme heat, and air conditioning use. In all cities, the most vulnerable populations are the elderly and the very young. (See also Figure 7.)

It has been suggested that winter mortality is likely to decline. Preliminary analyses suggest that this offsetting effect will not likely overwhelm the increase in summertime deaths. However, this effect needs to be studied further.

It is noteworthy that even under current conditions, the U.S. public health care system is not completely effective at preventing heat-related illnesses and deaths. People die every year from heat stress in the United States. This fact must be considered when assessing our ability to adapt to the additional stress of future climate change.

Climate change may also affect the risk of infectious diseases in different geographic areas. Climate change will affect both the geographic range of "vectors" (such as mosquitoes) that carry infectious diseases, and the life cycles of the vectors and the pathogens that are carried by the vectors. The IPCC has concluded that in the aggregate, climate change would increase the potential transmission of many vector-borne diseases globally. These diseases include, for example, malaria, dengue, yellow fever and some viral encephalitis.

There are those who are understandably skeptical about the potential spread of infectious diseases in the U.S. and Canada as a result of climate change. But it is important to understand that we are not making predictions about future outbreaks of infectious diseases. Other socioeconomic factors, such as the quality of our health care systems, will affect whether or not outbreaks actually occur. We are talking about changes in risks due to climate change.

Particular regions of the U.S. are already at risk from some infectious diseases. Weather conditions in these regions are conducive to the transmission of particular diseases. Also, with modern international transportation, the vectors that carry diseases, as well as the diseases themselves, can be introduced to different regions of North America.

It is noteworthy that there have, in fact, been cases of infectious diseases like St. Louis Encephalitis and hantavirus in the U.S., and they have been associated with specific weather patterns. Many of these are the sorts of weather patterns that one would expect to increase in frequency with climate change.

It is true that our health care systems can be a deterrent to the spread of infectious diseases. But effective health care systems come at a cost. The resources used to reduce the additional risks posed by climate change must be diverted away from other productive activities. There are also questions about the effectiveness of adaptive responses. As illustrated in Figure 6, people are dying of heat stress under current conditions, even though many of these deaths are preventable.

Climate change will make it more challenging for health care systems to protect public health.

Sea Level Rise

Sea level is expected to rise even more as a result of climate change. A 1997 EPA study estimated probabilities associated with future sea level rise along the continental U.S. (Figure 8).

There is a regional texture to future sea level rise across the U.S. For example, there is a 50% probability that sea level will rise 22 inches along New York by the year 2100, but there is a 50% probability that sea level will rise 55 inches along Grand Isle, Louisiana.

What does this potential sea level rise put at risk? The projected average global sea level rise of 20 inches could inundate 5,000 square miles of dryland and drown 15 - 60% of our coastal wetlands. Whether or not these losses are incurred will also depend upon other stressors, such as land use patterns. For example, structures that are being built behind existing wetlands will prevent migration of the wetlands as sea level rises. Once again, climate change is an additional stressor.

As noted earlier, the effects of climate change may already be occurring. The sea is already rising and wetlands are already being affected. Figure 9 is an illustration of the Blackwater National Wildlife Refuge as it appeared in 1938 and 1980. Upland and marshlands have been lost as a result of sea level rise and other factors. These changes pose risks to fish and wildlife habitat, flood and erosion control, and water quality. The key message is that sea level rise, which is partly induced by human activities, is real. It is already occurring.

Water Resources

Water quantity and quality, a "linchpin" that integrates many regions and sectors, are particularly vulnerable to climate change. Water quantity and quality will be directly affected by precipitation changes and increased evaporation. With an intensification of the hydrologic cycle, floods will be more likely due to more intense rainfall. Droughts will be more severe due to increased evaporation and drier soils. The degree to which water quantity and quality will be affected will be region specific.

In addition, water supplies will be indirectly affected. A lot of different sectors use water. As water becomes more scarce in some areas, and as different sectors increase their demands for that water, there will be additional stresses on available water supplies. This has important implications for the viability and effectiveness of different adaptation strategies in different sectors. For example, an increased scarcity of water may limit the ability of "smart farmers" to adapt to climate change through increased irrigation. The water that is important to farmers is also important for hydropower, urban water supplies, fish habitat and other ecosystems, and recreational activities.

Water is also habitat for fish. A recent study by the EPA examined the potential impact of climate change on freshwater fish in rivers and streams in the U.S. (Figure 10). The study found that cold- and cool-water fish of varying types are vulnerable to climate change. For example, under one (GFDL) climate change scenario, the populations of brown trout declined from 1% to 100% in a $2xCO_2$ world in every state included in the analysis. These losses have important implications for recreational fishing and translate into economic impacts. In the U.S., economic losses due to changes in recreational fishing opportunities could be on the order of tens of millions of dollars per year.

The key message is that water is a linchpin that links many different sectors together and influences the vulnerability of these sectors to climate change.

Agriculture

An examination of the agriculture sector helps to illustrate the limits of our understanding of climate impacts, as well as the difficulties that may exist to adapting to climate change.

Most studies suggest that in the aggregate, climate change will benefit U.S. agriculture. This is particularly true if one accounts for international trade and the declines in agricultural productivity that are likely to occur in developing countries. However, by itself, this generally-accepted conclusion is misleading because it fails to convey the regional distribution of agricultural impacts within the U.S. There will be a regional texture to potential agricultural impacts. Even though the United States as a whole will be a winner, some regions may be net losers. There will also be distributional impacts within any particular region. For example, under the climate scenario depicted in Figure 11, farmers who plant wheat in Texas may experience increases in yields (as opposed to total output) as a result of climate change. But farmers who plant corn in Texas may experience declines in yields.

Although the potential implications of climate change for U.S. agriculture have been extensively studied, it is important to understand the limitations of existing studies. Most studies have examined the effects of changes in average climate. They have not fully accounted for changes in climate variability. Many studies also make strong assumptions about the ability of farmers to adapt, but have not fully accounted for changes in water availability (which is necessary for irrigation), and imperfect responses by farmers to changing climate (*e.g.*, due to changes in climate variability). Warmer climates and less soil moisture due to increased evaporation may increase the need for irrigation. However, these same conditions could decrease water supplies, which also may be needed by natural ecosystems, urban populations, and other economic sectors. All of these issues deserve further study.

Conclusion

There are several key "take-away" messages from this presentation. First, the vast majority of scientists agree that climate change is a real phenomenon. Second, some human-induced climate change appears inevitable. We are affecting the Earth's atmosphere and the climate system. It is not yet possible to say how much of the historic change in climate is attributable to human activities. But a human "fingerprint" has been detected. Third, we may already be seeing the first discernible signs of climate change and the resulting impacts. Climate change has implications for the current generation, as well as future generations. Fourth, it is very hard to predict exactly where, when, and how large the impacts will be. However, we are already able to provide valuable insights to stakeholders and resource managers about the risks posed by climate change. Decisions about investments in adaptation can be made given information that is already available. Fifth, human-induced climate change would be slow to reverse.

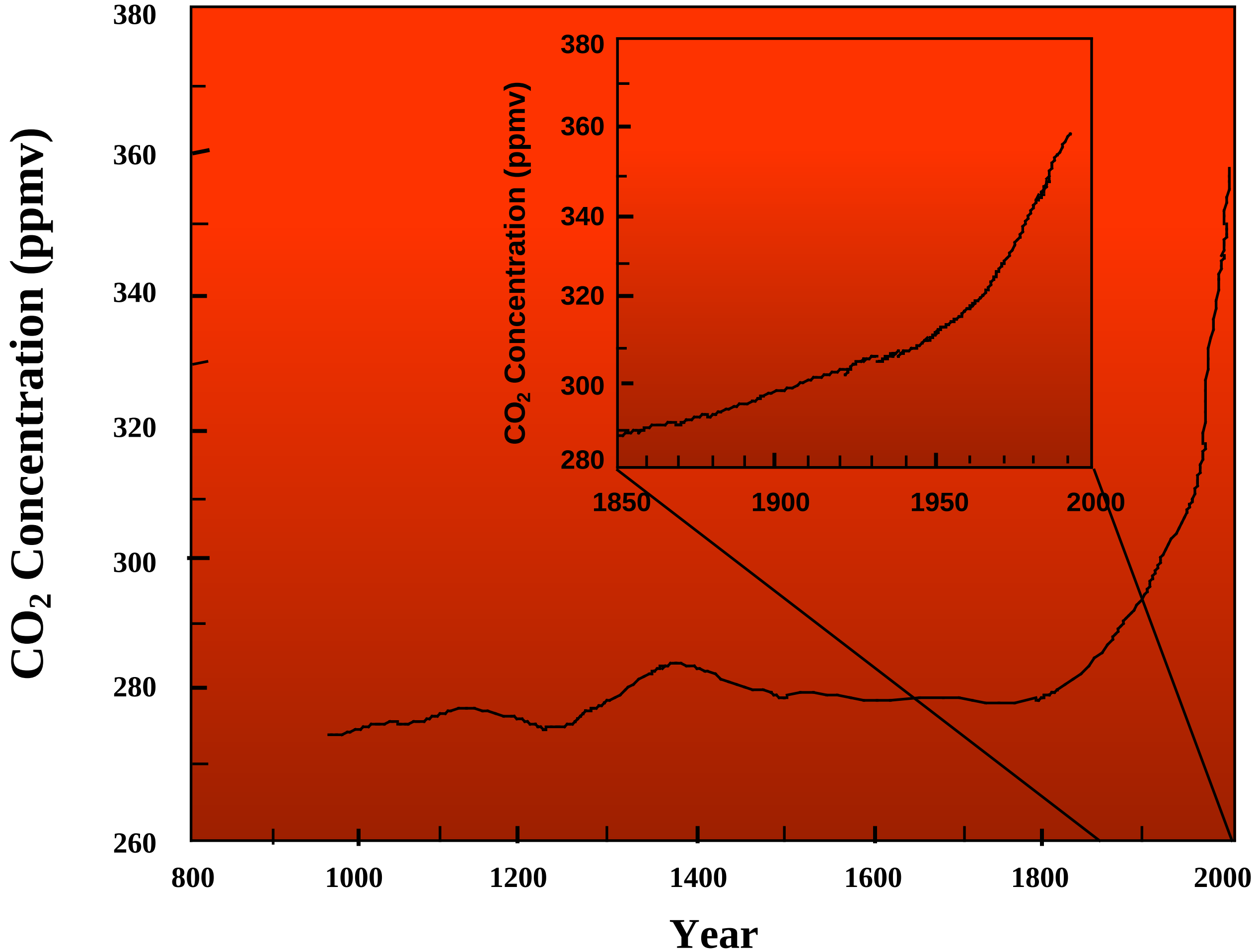
Is this a message of "doom and gloom"? No. I suggest that in order to make intelligent policy decisions, one must understand the consequences of inaction.

As international deliberations continue about possible actions to mitigate climate change – which comes at a cost – people will ask, "What are we buying?" A better understanding of the risks posed by climate change can help inform these deliberations. Although there is no such thing as a "free lunch," that doesn't mean that we don't want to buy lunch. It just means that we want to know what lunch we are buying.

It is also important to understand the potential impacts of climate change in order to make sensible decisions about adaptation. Some adaptation will be necessary since we are already committed to some human-induced climate change. We need to understand what the risks are and who the vulnerable populations are, in order to intelligently design adaptation options.

This isn't a doom and gloom message. This is an effort to communicate the potential impacts of climate change so that we can make intelligent and informed policy decisions.

CO_2 Concentrations Over the Past 1000 Years



Source: Based on IPCC (1994)

Figure 1

Examples of Greenhouse Gases Affected by Human Activities

	CO_2	CH_4	N_2O
Pre-industrial concentration	280 ppmv	700 ppbv	275 ppbv
Concentration in 1994	358 ppmv	1720 ppbv	312 ppbv[2]
Rate of concentration change[1]	1.5 ppmv/yr	10 ppbv/yr	0.8 ppbv/yr
Atmospheric lifetime (years)	50-200[a]	12[b]	120

ppmv = part per million volume; ppbv = part per billion volume

[1] The growth rates of CO_2, CH_4 and N_2O are averaged over the decade beginning in 1984.

[2] Estimated from 1992-1993 data.

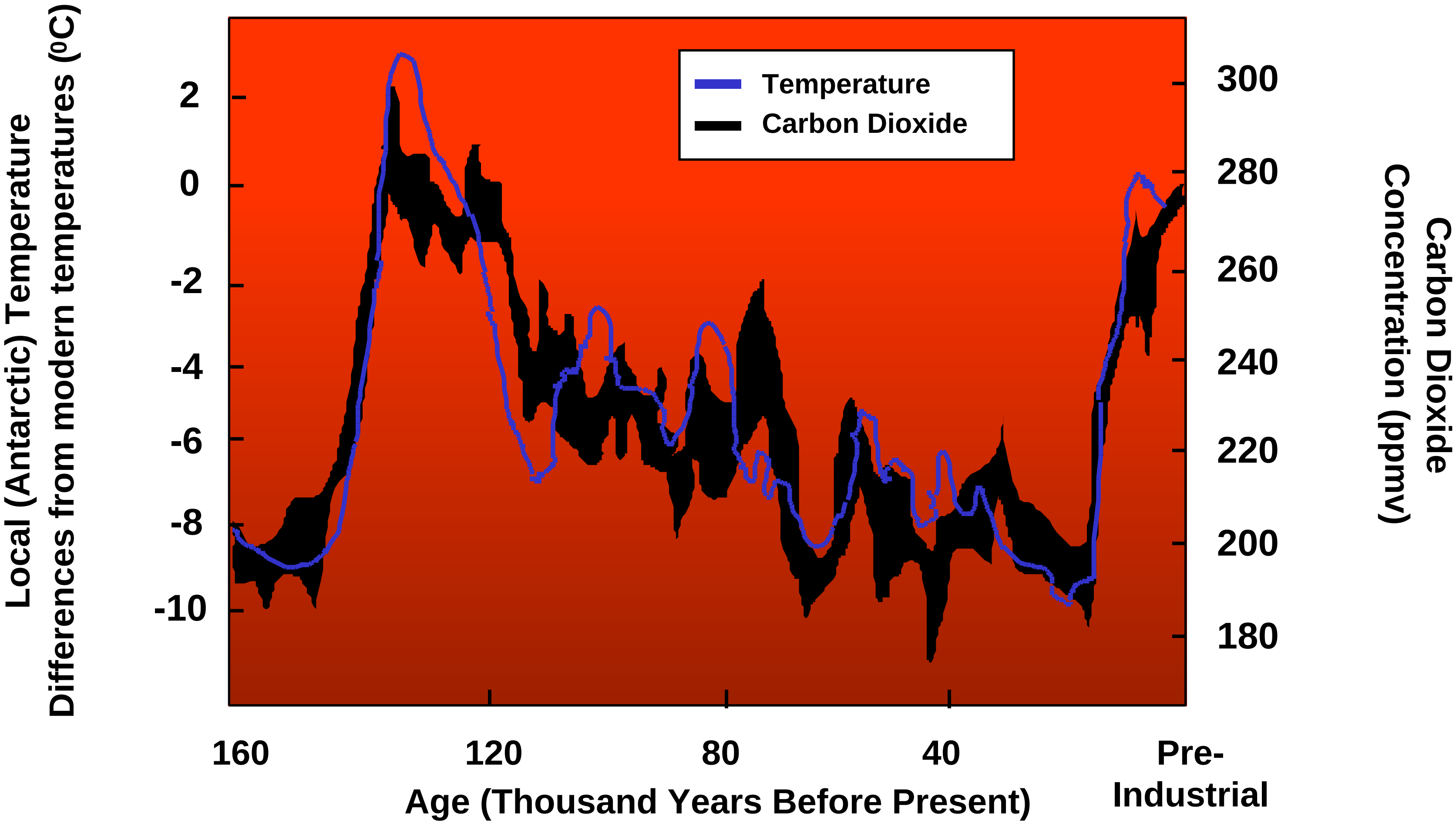
[a] No single lifetime for CO2 can be defined because of the different rates of uptake by different processes.

[b] Defined as an adjustment time which takes into account the indirect effects of methane on its own lifetime.

Source: IPCC, 1995

EPA

Local Temperature Change and CO_2 Concentrations Over the Past 160,000 Years

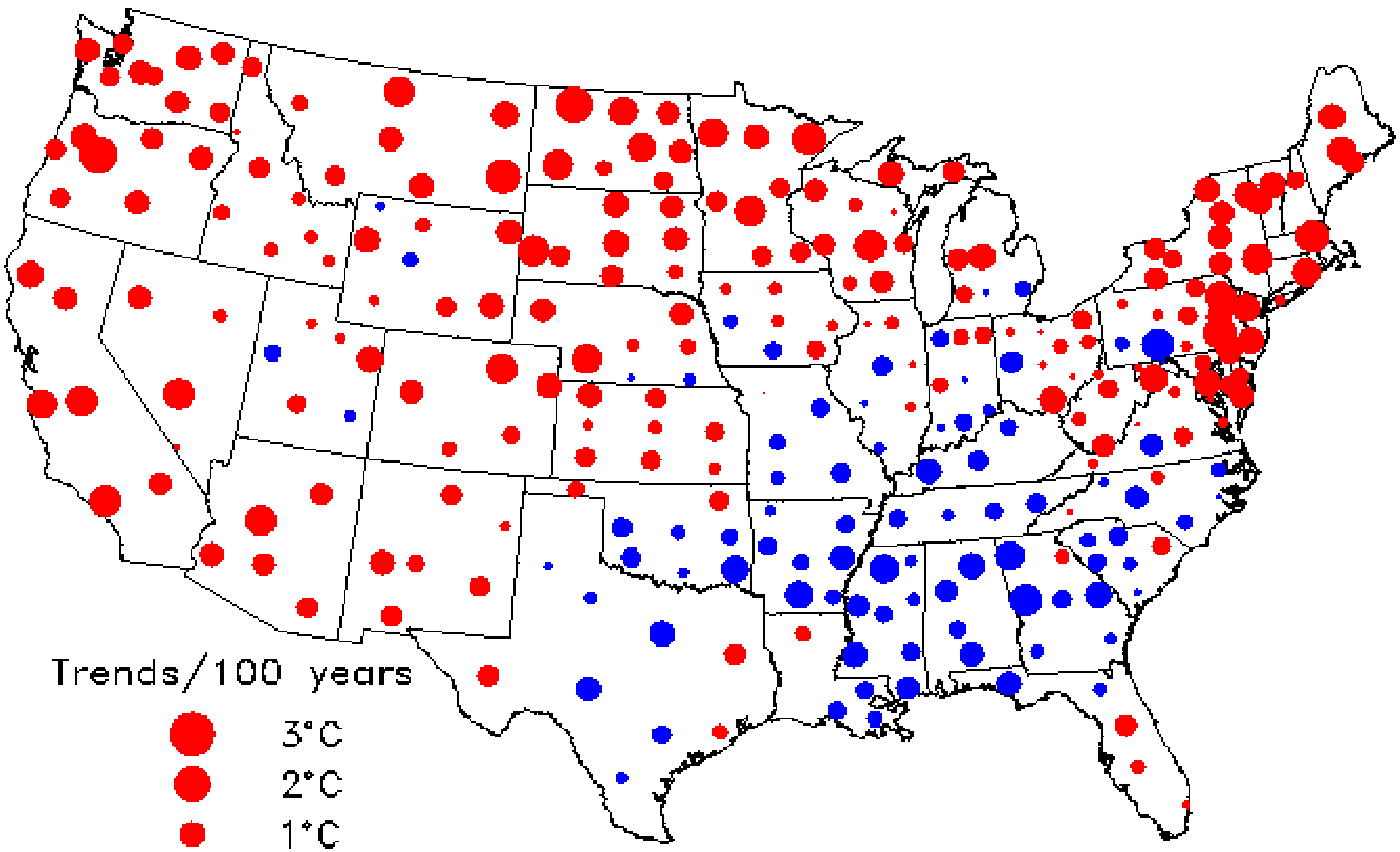


Derived from Antarctic ice cores

Source: Based on IPCC (1990)

Figure 2

Temperature Trends: 1900 to Present

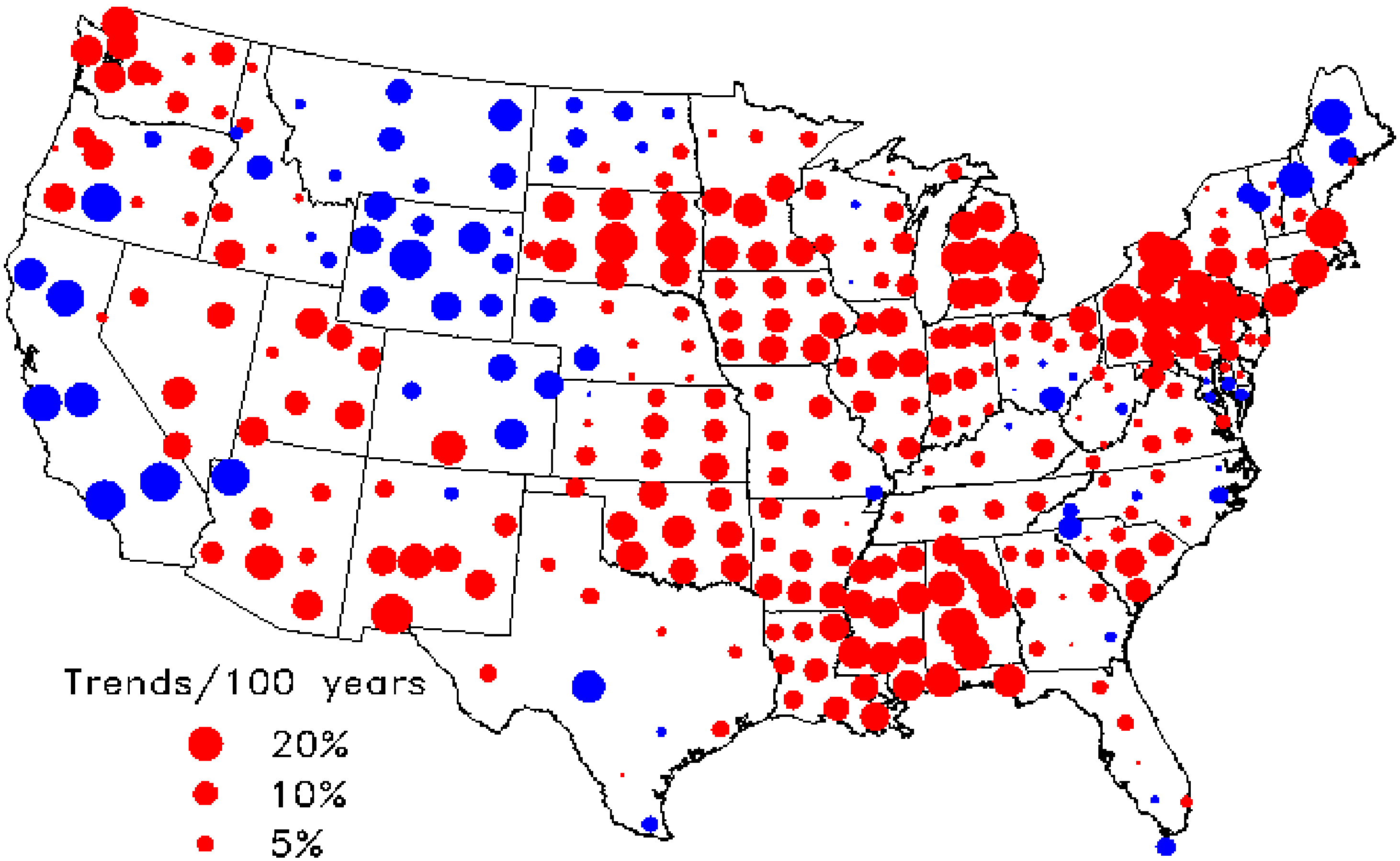


Red circles reflect warming;
Blue circles reflect cooling

Source: Karl et al. (1996)

Figure 3

Precipitation Trends: 1900 to Present



Red circles reflect increasing precipitation;
Blue circles reflect decreasing precipitation

Source: Karl et al. (1996) **Figure 4**

Potential Climate Change Impacts

Climate Changes

Temperature

Precipitation

Sea Level Rise

Health Impacts

Weather-related Mortality
Infectious Diseases
Air Quality-Respiratory Illnesses

Agriculture Impacts

Crop yields
Irrigation demands

Forest Impacts

Change in forest composition
Shift geographic range of forests
Forest Health and Productivity

Water Resource Impacts

Changes in water supply
Water quality
Increased Competition for water

Impacts on Coastal Areas

Erosion of beaches
Inundate coastal lands
Costs to defend coastal communities

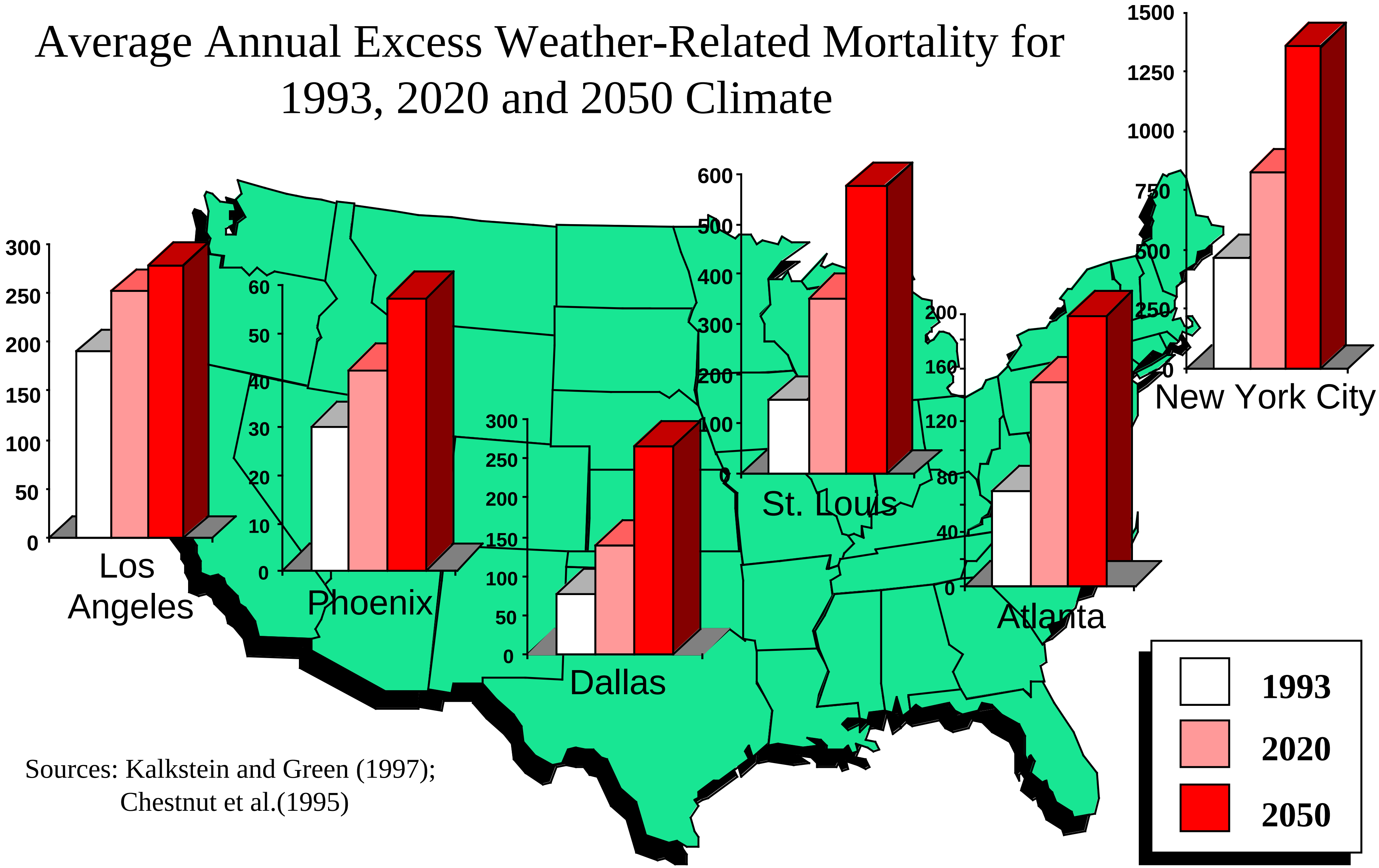
Species and Natural Areas

Shift in ecological zones
Loss of habitat and species

EPA

Figure 5

Average Annual Excess Weather-Related Mortality for 1993, 2020 and 2050 Climate



Sources: Kalkstein and Green (1997);
Chestnut et al.(1995)

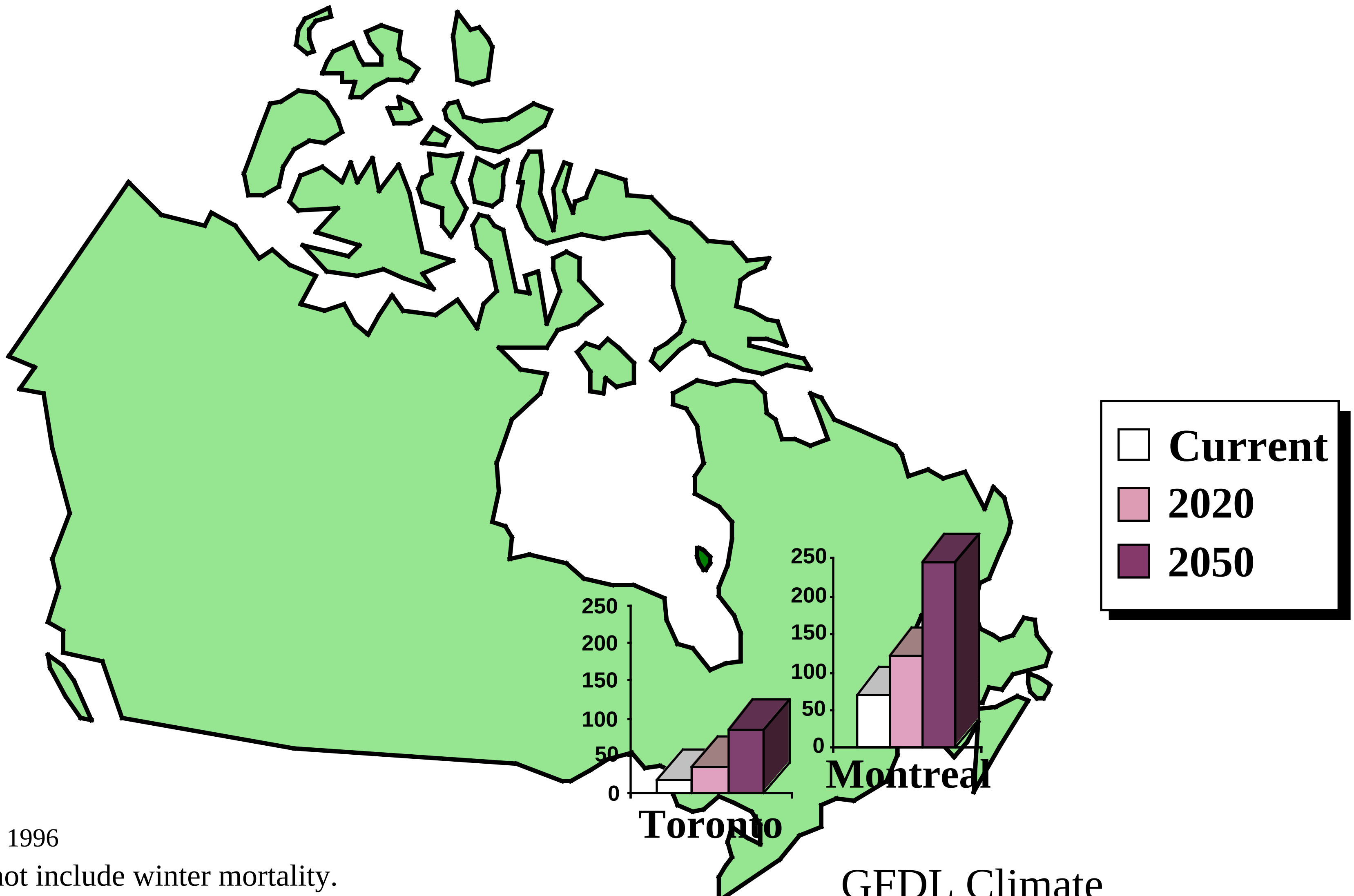
Note: Includes both summer and winter mortality.
Assumes full acclimation to changed climate.
Includes population growth.

GFDL Climate Change Scenario

Figure 6

EPA

Summer Heat-Related Mortality for Current, 2020, and 2050 Climate



Source: WHO, 1996

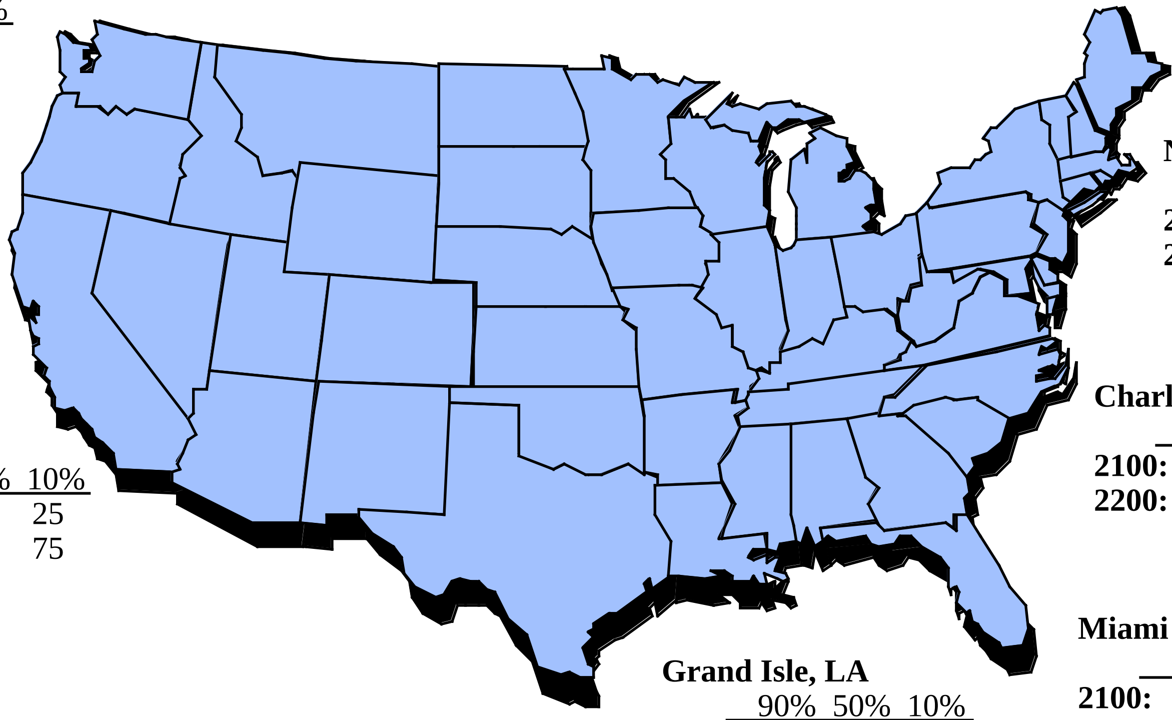
Note: Does not include winter mortality.
Assumes no acclimatization to changed climate.
Does not account for population growth.

Figure 7

GFDL Climate Change Scenario

EPA

Probability of Sea Level Rise



Seattle, WA

	90%	50%	10%
2100:	9	19	30
2200:	19	42	85

San Fransisco, CA

	90%	50%	10%
2100:	6	15	27
2200:	13	36	79

Los Angeles

	90%	50%	10%
2100:	4	13	25
2200:	9	32	75

Portland, ME

	90%	50%	10%
2100:	10	19	31
2200:	20	43	87

New York, NY

	90%	50%	10%
2100:	12	22	33
2200:	24	48	91

Charleston, SC

	90%	50%	10%
2100:	15	25	36
2200:	30	53	97

Miami Beach, FL

	90%	50%	10%
2100:	10	20	32
2200:	21	44	88

Grand Isle, LA

	90%	50%	10%
2100:	46	55	67
2200:	89	112	155

Estimates are in inches.

Source: U.S. EPA (1995).

Figure 8

EPA

Blackwater National Wildlife Refuge (Maryland)

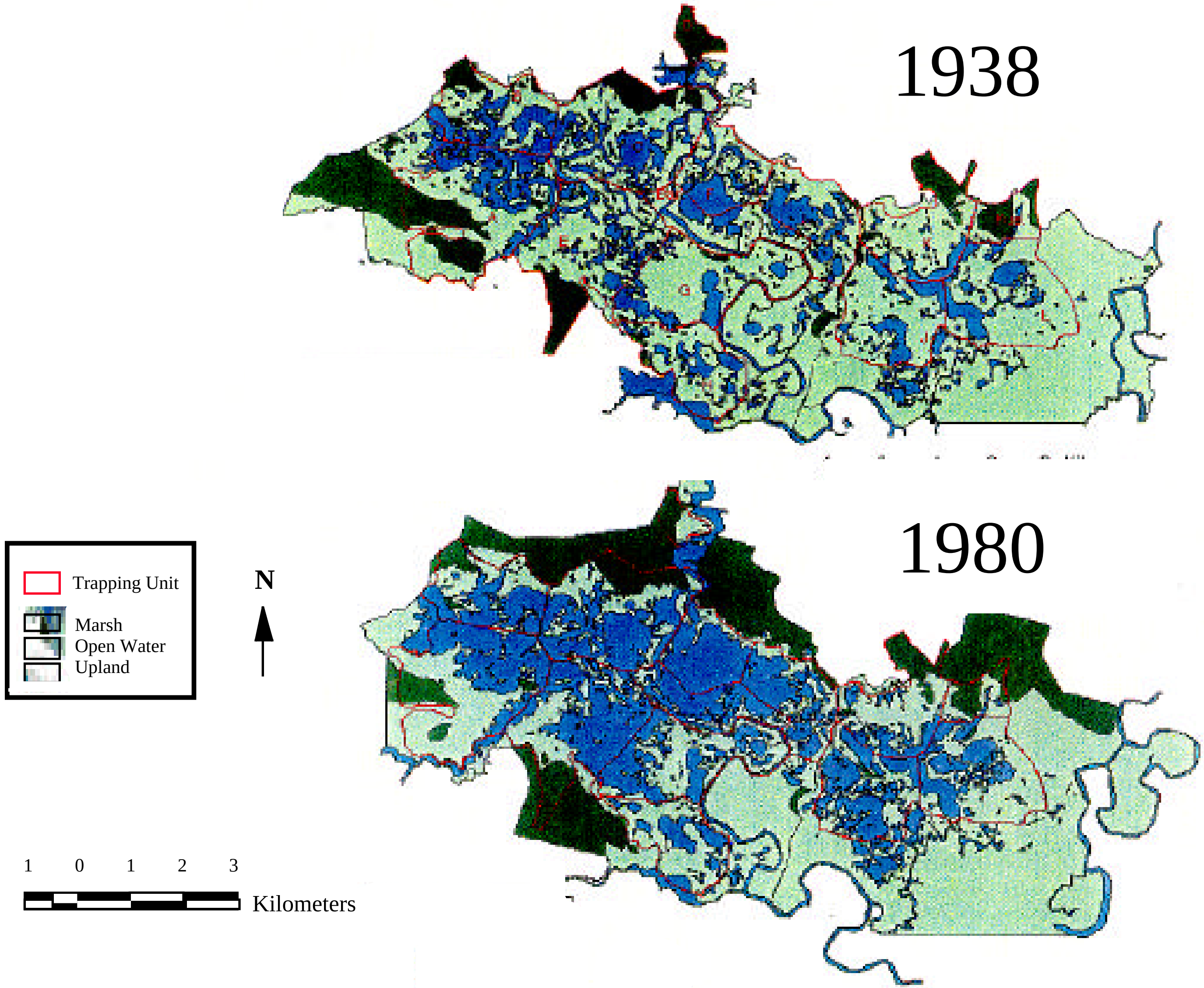
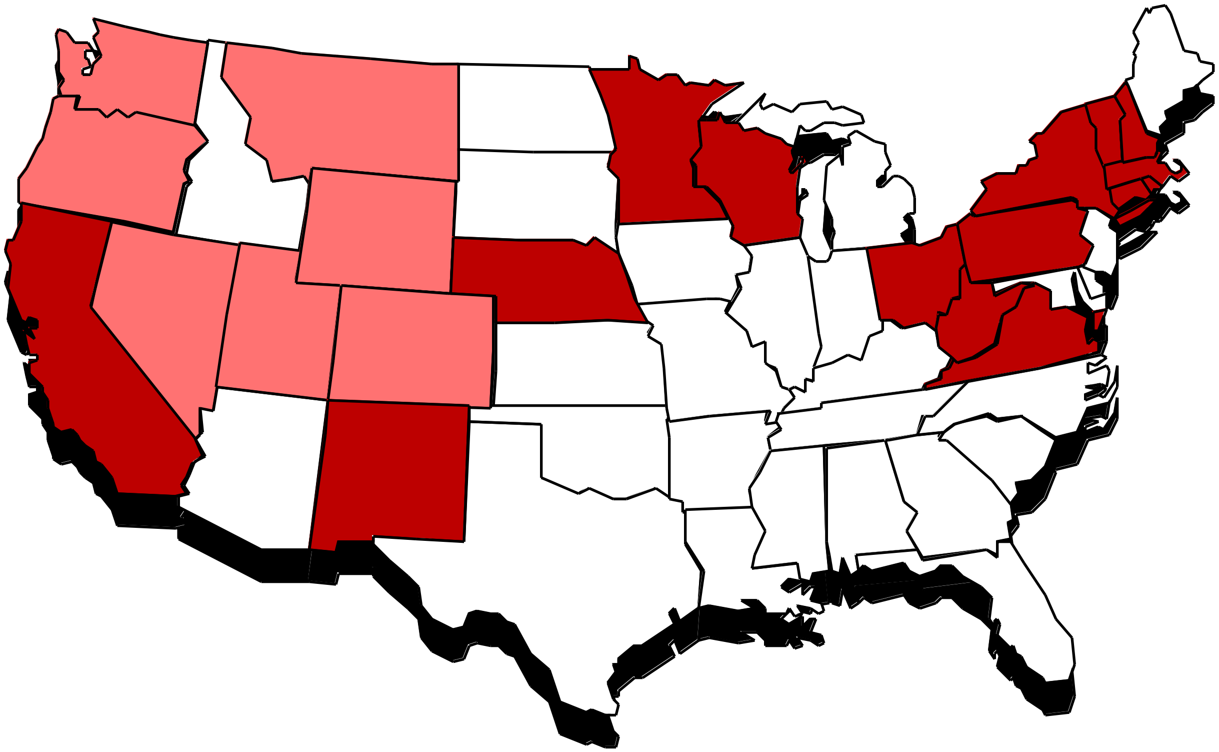


Figure 9

Loss of Habitat for Brown Trout from a Doubling of CO_2 - 2050



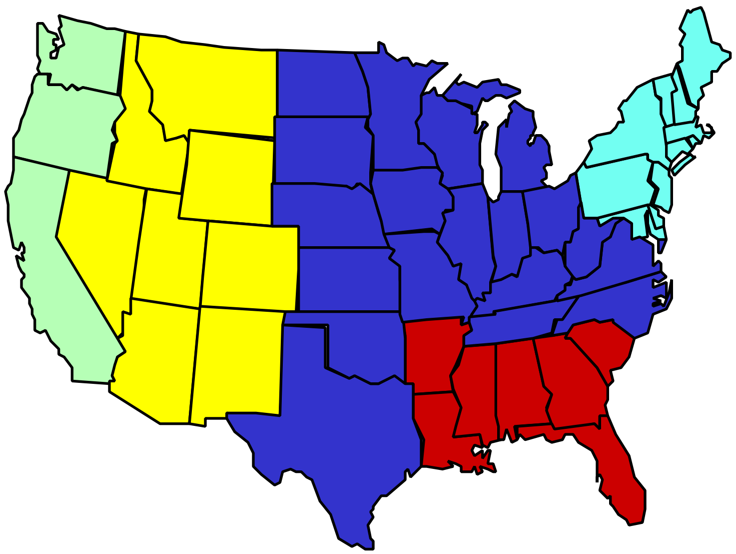
Not included in analysis *	
1-49% Loss	
50-100% Loss	

* Dual screening criteria used for inclusion: 1) Thermal modeling predicts suitability and 2) Fish presence in 10% or more of State's water bodies.

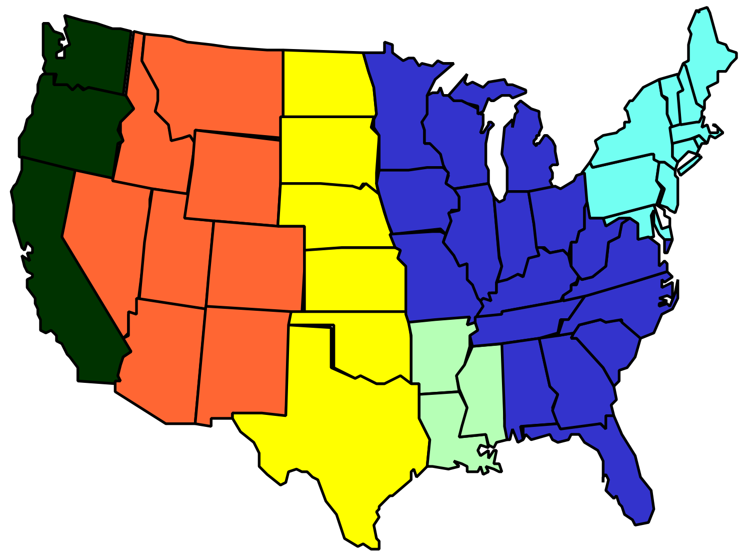
Source: EPA, 1995 **Figure 10** GFDL Climate Change Scenario EPA

Changes in Agricultural Yields

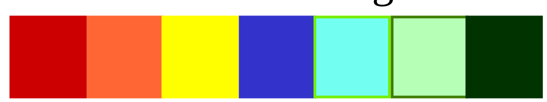
Change in Wheat Yield



Change in Corn Yield



Percent Change



+ 2.5^{o}C
+ 7% Precipitation
530 ppmv CO_2

Source: Rosenzweig, 1995

Figure 11