Oregon Climate Assessment Report

December 2010

Oregon Climate Change Research Institute

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About the Oregon Climate Change Research Institute

The Oregon Climate Change Research Insititute (OCCRI) is a network of over 100 researchers across the Oregon University System and affiliated state and federal labs. OCCRI was established in 2007 by the Oregon State Legislature to foster climate change research across the Oregon University System.

OCCRI is housed in the College of Oceanic and Atmospheric Science at Oregon State University

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Oregon Climate Assessment Report

Legislative Summary

Earth's climate has changed in the past, though the recent magnitude and pace of changes are unprecedented in human existence. Recent decades have been warmer than at any time in roughly 120,000 years. Most of this warming can be attributed to human activity, primarily burning fossil fuels (coal, oil and natural gas) for energy. Burning fossil fuels releases carbon dioxide and other heat trapping gases, also known as greenhouse gases, into the atmosphere. This warming cannot be ascribed to natural causes (volcanic and solar) alone. It can be said that human activities are primarily responsible for the observed 1.5 ˚F increase in 20th century temperatures in the Pacific Northwest. A warmer climate will affect this state substantially.

Future regional climate changes in Oregon include:

Increases in temperature around 0.2-1˚F per decade

Average annual air temperatures will increase through the 21st century. The amount of warming depends partly on the rate of greenhouse gas emissions.

Warmer and drier summers

Seasonal changes of climate are typically more relevant for decision makers and for studying impacts. The most consistent changes in global climate models show a regional warming and drying in the summer. The multi-model average decrease for summer precipitation is 14% by the 2080s.

There is some evidence that extreme precipitation will increase in the future

Though trends in extreme daily precipitation over the 20th century have been ambiguous in Oregon, there is some indication that such events will increase in the 21st century.

Sea level rise

It is near certain that global mean sea level will increase, possibly by 2-4 feet by 2100. By the mid 21st century, the rate of sea level rise will exceed vertical land movement on the Oregon Coast. Submerged areas will experience erosion and flooding impacts.

Key findings:

Summer water supply will decrease as a result of reduced snowpack and summer precipitation. The presence of a winter snowpack is crucial for summertime water supply in much of Oregon. A viable water supply is needed for irrigation, residential and commercial water use, fish propagation and survival and overall ecosystem health. Snowpack in the Pacific Northwest is particularly sensitive to warming. By mid-century, Cascade snowpacks are projected to be less than half of what they were in the 20th century, with lower elevation snowpacks being the most vulnerable. Water demands are projected to increase throughout the 21st century, particularly in urban areas, posing an additional stressor to water availability.

Availability, quality and cost of water will likely be the most limiting factor for agricultural production systems under a warmer climate. Many Oregon irrigation systems are fed by snowmelt and stored in reservoirs. With an increase in temperature irrigation demands will be greater. There may be new opportunities for agriculture in a warmer climate: the growing season may be extended and yields may be more plentiful. A potential opportunity exists for a longer growing season and yields may be greater. Oregon's wine regions have seen the length of the frost-free period increase from 17 to 35 days. However, more research is needed on irrigation technologies and new crop adaptations. Associated management of new invasive plant pathogens, insects and weeds is needed.

Wildfire is projected to increase in all Oregon forest types in the coming decades. Warmer and drier summers leave forests more vulnerable to the stresses from fire danger west of the Cascades. Wildfire in forests east of the Cascades is mainly influenced by vegetation growth in the winters that provides fuel for future fires. An increase in fire activity is expected for all major forest types in the state under climate change. Large fires could become more common in western Oregon forests.

Frequency and magnitude of coastal flooding events may continue to increase. Storminess and extreme storm events have been increasing, leaving coastal areas vulnerable to flooding and erosion. North Pacific winter storm track is projected to shift northward in the 21st century, meaning slightly fewer, but more intense storms.

Many plant and animal species on land, in freshwater, and in the sea have and will shift their distributions and become less or more abundant. In a warmer climate, plant and animal species may have to shift upward or northward on land, and deeper or northward at sea. Rare or endangered species may become less abundant or extinct; insect pests, invasive species and harmful algal blooms may become more abundant.

Changes to the marine environment including increasing water temperatures. Substantial increases in water temperatures in the ocean are likely and will exceed natural variability. The ocean also absorbs carbon dioxide (CO_2) from the atmosphere, which forms carbonic acid and is making waters corrosive to certain species.

Oregon's economy, like many other states, is likely to be affected by a changing climate and by policies addressing projected changes. There is still much work to be done in developing a complete assessment on the economic impacts of climate change in Oregon. However, the work to date suggests that climate change poses economic risks to the state. The magnitude of the impact will depend on the rate of physical change, the willingness of humans to alter their behaviors, and the resilience of our ecosystems.

The important drivers of greenhouse gas emissions are population, consumption, and the emission intensity of the economy (e.g. tons of equivalent carbon dioxide per unit of economic output).

We are already experiencing the impacts of climate change in Oregon. Given these observed and anticipated impacts, prudent measures to adapt should be taken now. Resilience needs to be built into human communities and fostered in natural communities to deal with the adverse impacts on of climate change. The State of Oregon has undertaken a substantial adaptation planning effort drawing heavily from the conclusions regarding the state of climate science found in this report.

The full report can be obtained by calling Julie Cope at the Oregon Climate Change Research Institute at 541-737-5705 and is available for download at www.occri.net/ocar.

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Executive Summary

The group of scientists that make up the Intergovernmental Panel on Climate Change found in 2007 that the warming of Earth's climate is unequivocal and largely due to human activity. Earth's climate has changed in the past, though the recent magnitude and pace of changes are unprecedented in human existence. Recent decades have been warmer than at any time in roughly 120,000 years. Most of this warming can be attributed to anthropogenic activity, primarily burning fossil fuels (coal, oil and natural gas) for energy. Burning fossil fuels releases carbon dioxide and other heat trapping gases, also known as greenhouse gases, into the atmosphere. This warming cannot be explained by natural causes (volcanic and solar) alone. It can be said with confidence that human activities are primarily responsible for the observed 1.5 ˚F increase in 20th century temperatures in the Pacific Northwest. A warmer climate will affect this state substantially.

In 2007, the Oregon State Legislature charged the Oregon Climate Change Research Institute, via HB 3543, with assessing the state of climate change science including biological, physical and social science as it relates to Oregon and the likely effects of climate change on the state. This inaugural assessment report is meant to act as a compendium of the relevant research on climate change and its impacts on the state of Oregon. This report draws on a large body of work on climate change impacts in the western US from the Climate Impacts Group at the University of Washington and the California Climate Action Team. In this report, we also identify knowledge gaps, where we acknowledge the need for more research in certain areas. We hope this report will serve as a useful resource for decision-makers, stakeholders, researchers and all Oregonians. The following chapters address key sectors that fall within the biological, physical and social sciences in the state of Oregon.

Chapter 1 - Climate change in Oregon's land and marine environments

Earth's climate has changed in the past, though the recent magnitude and pace of changes are unprecedented in human existence. Recent decades have been warmer than at any time in roughly 120,000 years. Most of the recent warming can be attributed to human activity - primarily burning fossil fuels (coal, oil and natural gas) for energy. Burning fossil fuels releases carbon dioxide and other heat trapping gases, also known as greenhouse gases, into the the atmosphere. The warming cannot be described by natural causes (volcanic and solar) alone. To confirm this, scientists can perform simulations of past and present climate using GCMs. They run these simulations using both natural and human influences (top panel, figure 1) and compare them to the observed temperature record (black line, figure 1). Running the simulation with only natural forcing (bottom panel, figure 1) does not replicate the observed temperature record; there are marked differences after 1960. Major volcanic eruptions are marked on each plot. These eruptions can cool the earth for one to two years, as demonstrated by the short-term dips in the observed temperature on the plot. The other major natural forcing on climate, solar activity, has not increased over the last 32 years. There are other, empirical methods that do not use global climate models that attribute the warming of the past few decades to human influences as well. The climate system has responded in ways that would be expected with an observed warming: global sea levels rose, the oceans have gotten warmer, and the amount of water vapor in the atmosphere has increased (warmer air can hold more water vapor).

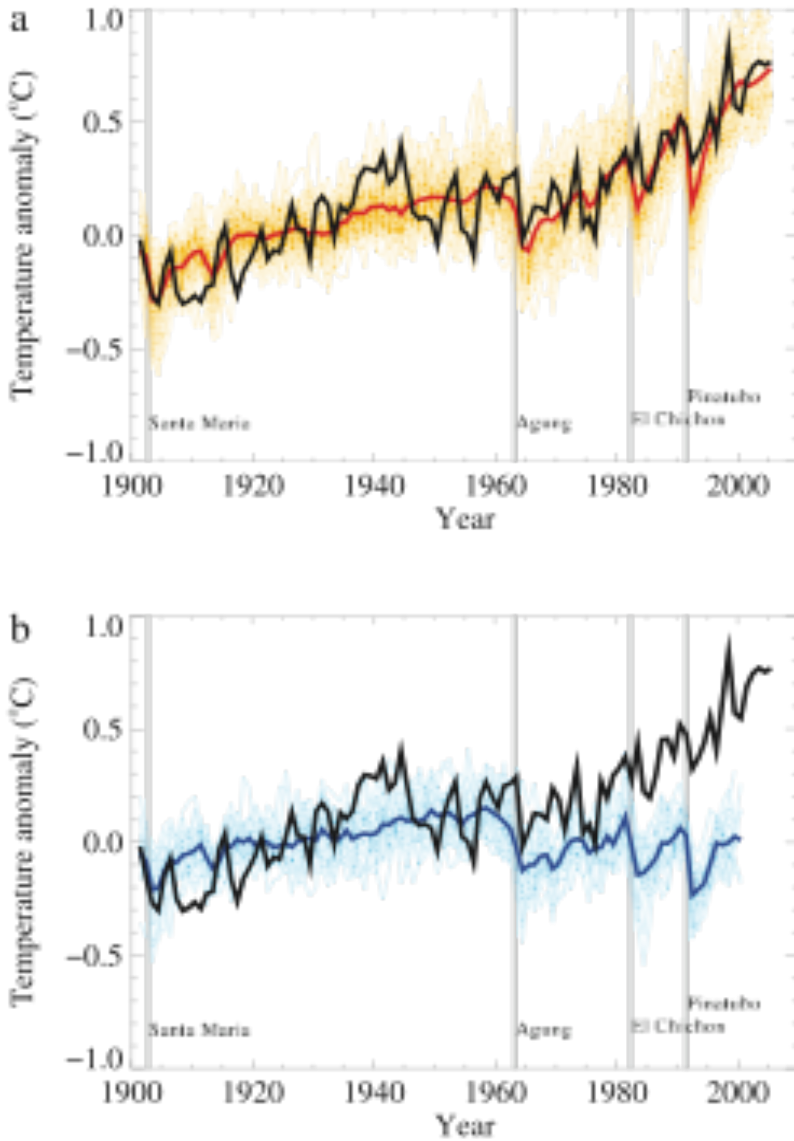

Figure 1. Comparison between global mean surface temperature anomalies (°C) from observations (black) and AOGCM simulations forced with (a) both anthropogenic and natural forcings and (b) natural forcings only. All data are shown as global mean temperature anomalies relative to the period 1901 to 1950, as observed and, in (a) as obtained from 58 simulations produced by 14 models with both anthropogenic and natural forcings. The multi-model ensemble mean is shown as a thick red curve and individual simulations are shown as thin yellow curves. Vertical grey lines indicate the timing of major volcanic events. The simulated global mean temperature anomalies in (b) are from 19 simulations produced by five models with natural forcings only. The multi-model ensemble mean is shown as a thick blue curve and individual simulations are shown as thin blue curves. From IPCC (Hegerl et al. 2007), Figure 9.5.

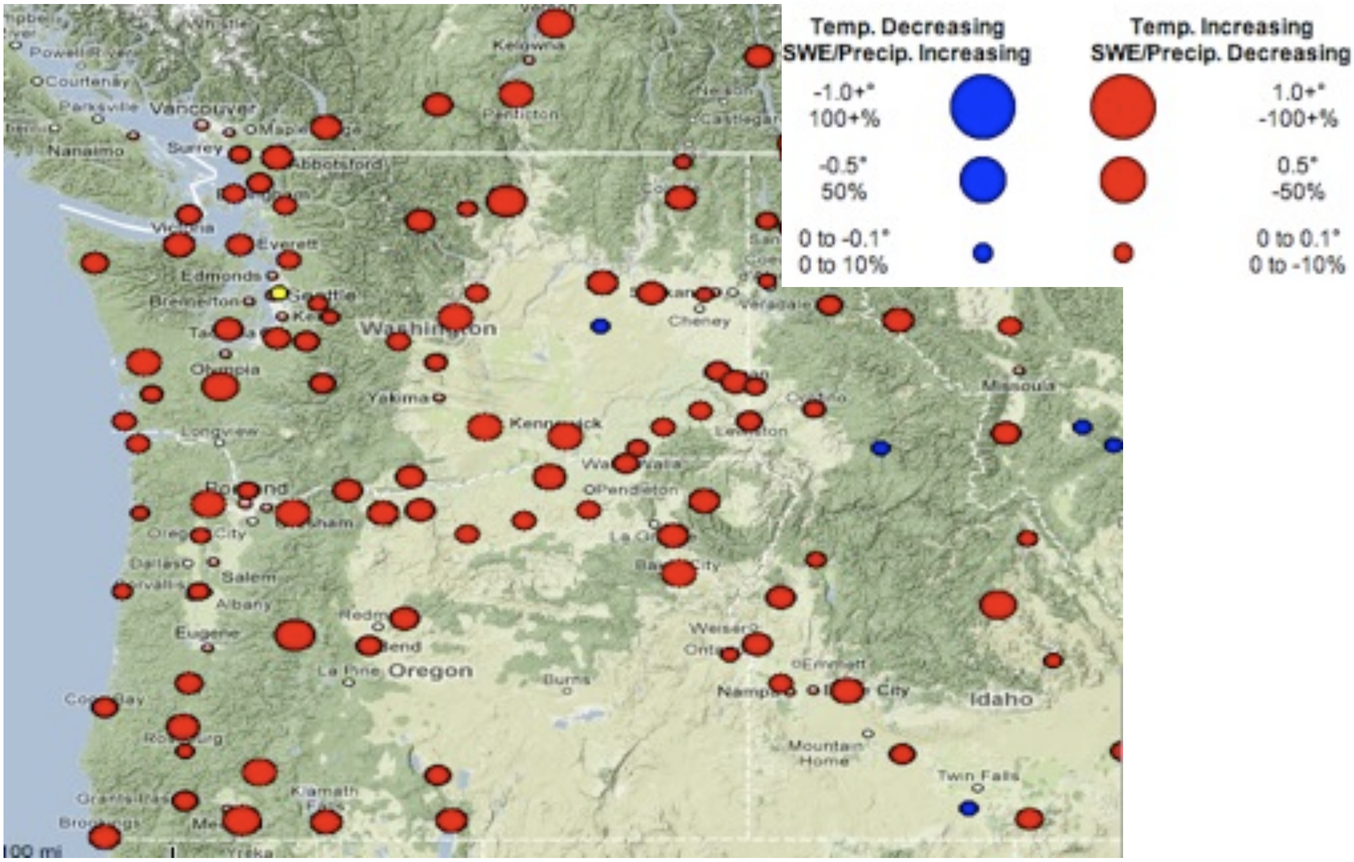

Figure 2. Linear trends in annual mean temperature at US Historical Climate Network stations in the Northwest. Red means warming, blue cooling, yellow no trend; size proportional to warming trend (°F/decade). Figures created using a utility at the Office of Washington State Climatologist, climate.washington.edu.

Oregon's climate can be defined as moderate, though varied with four distinct seasons. Mountain ranges dominate spatial patterns of climate in state. The Cascade range is the most influential, dividing the state roughly into two: the wetter west side, and more arid east side. The smaller, yet still significant Coast and Blue-Wallowa ranges also play a role. Most of the precipitation in the state falls between October and March. The coldest day of the year tends to fall around January 1 and the warmest on July 1. Temporal patterns of climate variability in Oregon are primarily influenced by the Pacific Ocean, namely ENSO (El Nino/Southern Oscillation).

Despite the spatial and temporal variability associated with the state's climate, the overall upward temperature trend over the last century is consistent with global carbon emissions; Oregon's climate is already changing. The observed 1.5 ˚F increase in the Pacific Northwest (1920-2003) is primarily due to human activities. Only a very small percentage of that temperature increase can be attributed to natural (Pacific) variability. Every station in the United States Historical Climatology Network in Oregon showed an increase in annual mean temperature over the 20th century (figure 2). While the increase in regional temperature is consistent with rising greenhouse gas concentrations, regionally averaged precipitation has fluctuated substantially. Additionally, trends in extreme precipitation are ambiguous and have received less attention from researchers.

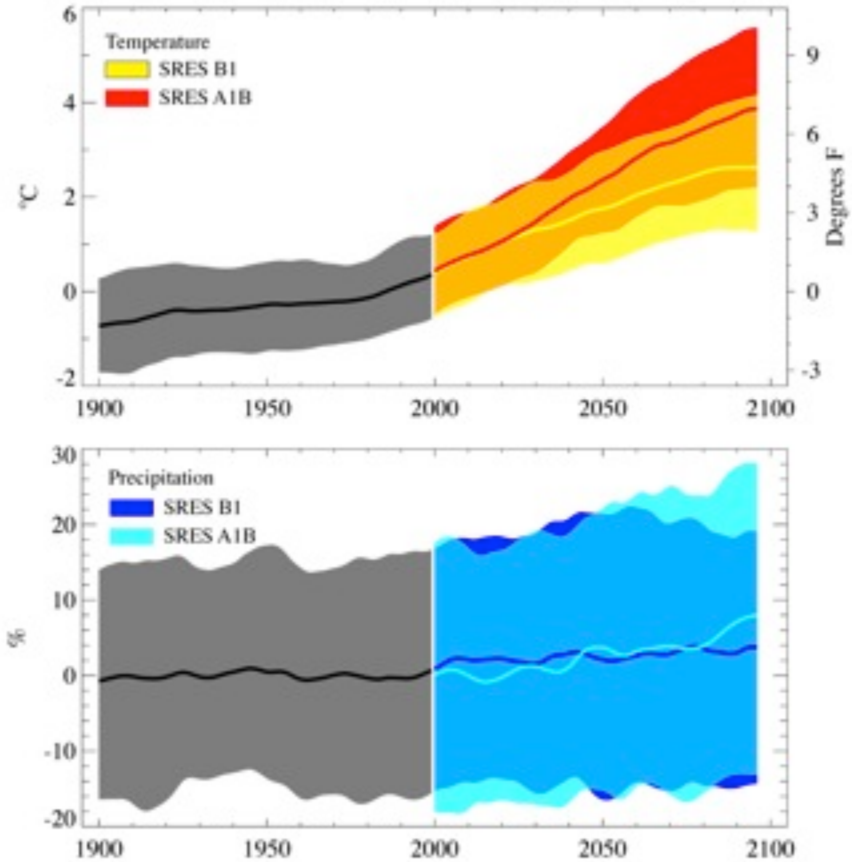

Figure 3 Smoothed traces in temperature (top) and precipitation (bottom) for the 20th and 21st century model simulations for the PNW, relative to the 1970-99 mean. The heavy smooth curve for each scenario is the weighted multi-model mean value, calculated for each year and then smoothed. The top and bottom bounds of the shaded area are the 5th and 95th percentiles of annual values (in a running 10-year window) from the ~20 simulations, smoothed in the same manner as the mean value. Mean warming rates for the 21st century differ substantially between the two SRES scenarios after 2020, whereas for precipitation the range is much wider than the trend and there is little difference between scenarios. From Mote and Salathé (2010).

Temperatures will continue to increase in Oregon through the 21st century. Projected temperatures for the next century are largely dependent on overall global carbon emissions. Without a substantial reduction in the activities that produce greenhouse gases, future regional change will likely be marked by increases in temperature around 0.5 ˚F per decade. The models suggest a warming of 3 ˚F (figure 2, yellow, b1 carbon emissions) to 10 ˚F (figure 3, red, continued aggressive carbon emissions). There is a a range associated with these projections, but the Pacific Northwest, and Oregon can expect at least some warming through the end of this century. There is a much larger range of uncertainty with annual precipitation. The models do not show a clear trend in annual precipitation for the region over the next century. Seasonal changes of climate tend to be of greater interest for decision makers and resource managers. Climate models point to hotter, drier summers.

Oregon's marine environment is is also influenced by natural variability. There are strong spatial variations, both vertically and horizontally. Temporal variability ranges from winds and tides to heating and cooling. Despite the ocean's inherently dynamic nature, there is evidence that Oregon's marine environment is changing. Some of these changes can be linked to global warming. Oregon State University oceanographers have studied the coastal waters for over 50 years and have observed significant changes over this time, including a warming consistent with rising air temperature, a freshening of the surface layer, and declines in dissolved oxygen. Given the year to year nature of the coastal ocean, there is still much work to be done in attributing changes to human or natural activity. Future changes will likely include substantial increases in ocean temperatures that far exceed natural variability.

Chapter 2 - Climate change in Oregon - Defining the problem and its causes

Human activities are driving most the recent global warming, largely through carbon emissions. Oregon has a relatively small population (28th in the US) and implies that its total greenhouse gas emissions are small compared to larger states. Oregon's total carbon emissions are 1% of US national emissions and 0.2% of global emissions. In light of this, per capita (or average per person) emissions should be used to compare Oregon against other states in the country. In terms of per capita emissions, Oregon's are the eleventh lowest in the country (about 20% lower than the national average). In comparing Oregon to other developed countries, its emissions rank much higher. The state's emissions are nearly double the European Community average and almost three times higher than the global average. One reason for the relatively small emissions from the European countries is high population density (also true in the United States). As urbanization increases, carbon intensity (or, amount of greenhouse gas per one dollar of gross state product produced) decreases. This is likely due to shorter commutes and the accessibility of mass transit. Oregon is the eleventh least carbon intensive economy in the country, but is the most carbon intensive of the contiguous West Coast states.

Oregon's contribution to global carbon emissions comes mostly through energy use - electricity consumption and transportation (figure 4). Most of Oregon's electricity comes from coal and hydropower. Transportation has been one of the single largest sources of greenhouse gases in Oregon over the last twenty years. In Oregon, the transportation sector accounts for 37% of greenhouse gas emissions. This is higher than the national average, in part, because Oregon's energy sector includes hydropower, which does not result in greenhouse gas emissions and reduces emissions from sectors other than transportation.

While transportation remains the largest source of greenhouse gas emissions in Oregon, driving habits have changed in recent years. Vehicle Miles Traveled (VMT) have been growing at a slower rate than the national average in Oregon and motor fuel consumption increased at a much smaller rate (.25%) than that of population growth (10.4 %). In Portland, the state's largest city, VMT started to decline in the mid-1990s. Improvements to mass transit also reduce greenhouse gases. Aside from electricity and transportation, waste management, agriculture and industrial sources all contribute to greenhouse gas emissions in Oregon, but in smaller amounts.

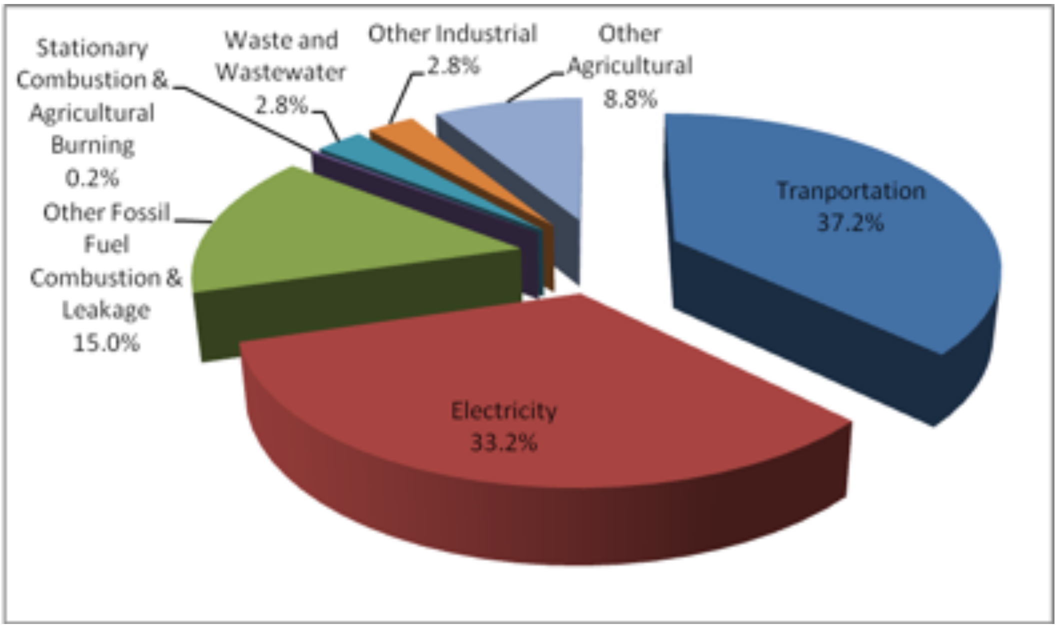

Fig. 4: Sources of greenhouse gases in Oregon. Data is averaged over 2003-2007, Oregon Greenhouse Gas Inventory, 2010.

The magnitude and impacts of climate change in the state are dependent on global carbon emissions. As a consequence, Oregon could not by itself reduce the impacts of climate change: policies will need to be enacted on the national and global scale to reduce the impacts of climate change. Since climate does not rapidly respond to year by year changes of emissions, a ten year aggregate emissions goal could be set. Lastly, given the disparity in per capita versus total emissions, state goals should be set to per capita emissions. This would reward states that make reductions in emissions while attracting economic growth and inward migration as opposed to states that reduce emissions by outward migration or economic downturn. Oregon's population is projected to grow by 13% by 2020, and it is estimated that 63% of that will be due to net migration into the state. If each state adopted this metric, national inventories could still be met and it would allow for a more equitable policy that does not hinder or discourage economic growth.

Chapter 3 - Climate Change and Freshwater Resources in Oregon

Water resources in Oregon and the western US have always been climate sensitive. The state receives most of its precipitation from October to March, meaning that it must rely on water storage in mountain snowpack to provide sufficient surface water resources in the summer months. The presence of a robust winter snowpack is crucial for summertime water supply. The amount and seasonality of water supply is projected to shift with seasonal changes in temperature and precipitation. It is important to note that not all past trends in streamflow can be attributed to global climate change; there is some interannual variability at play. Recent low flow years, particularly 2001 and 2005, stemmed from low winter precipitation. Snowmelt-related hydrologic variables already show a decline - earlier peak flow, lower summer flow, lower spring snowpack.

In the future, as winter temperatures warm, mountain snowpacks will diminish and summer water supply will likely decline. Earlier spring snowmelt will shift the timing of peak flows; some streams will peak earlier in the year. A decrease in summer precipitation is also likely in the future, which means the small amount of precipitation that the state receives in the summer will be even less in the future.

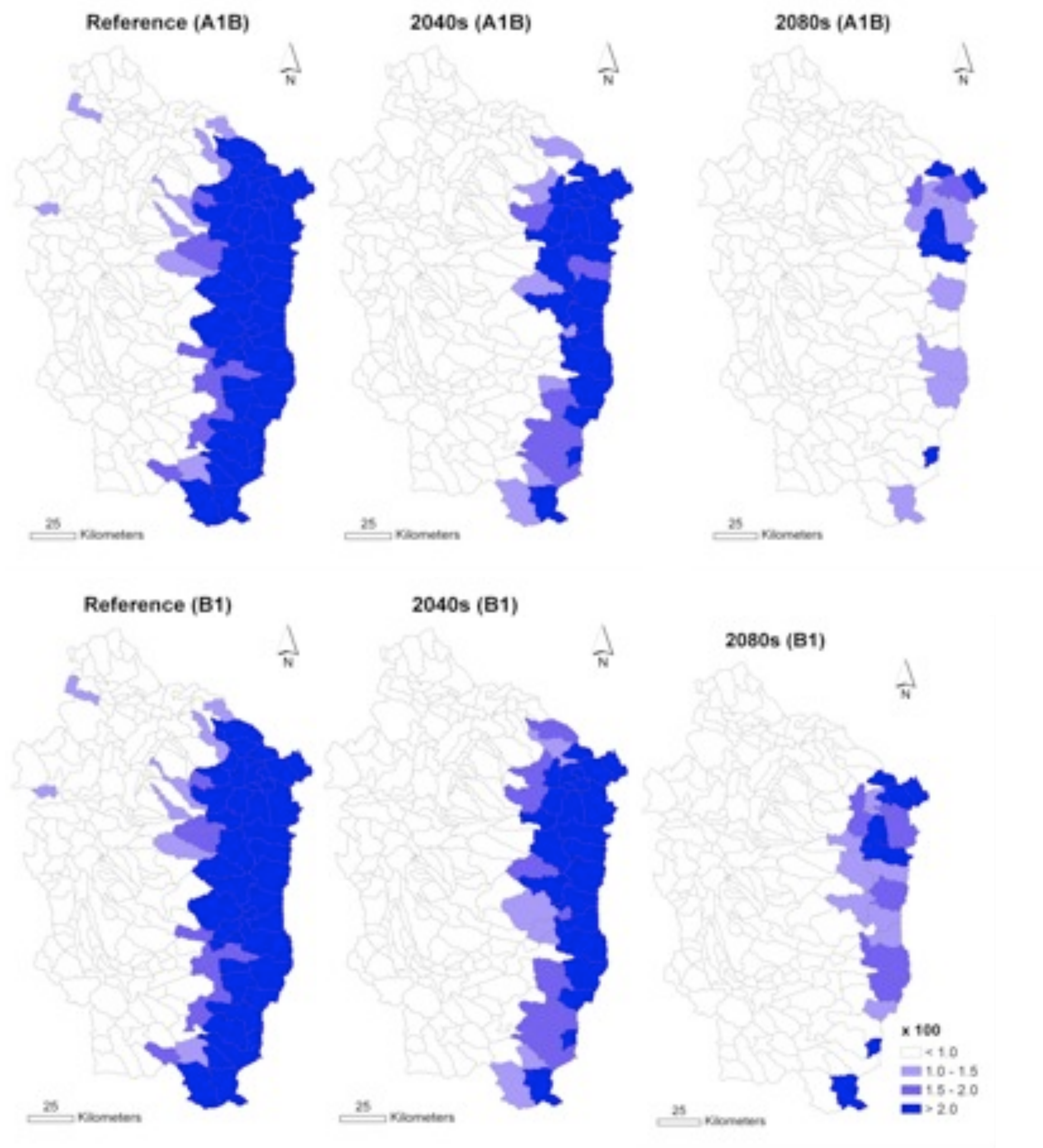

Figure 5 Ensemble mean changes (averaged over eight global climate models) in snow water equivalent in the Willamette River basin for historical (reference), the 2040s, and the 2080s by GHG emission scenario. The ratio is multiplied by 100 for representation (Source: Chang and Jung 2010).

A viable water supply is needed for irrigation, residential and commercial water use, fish propagation and survival and overall ecosystem health. With a (1.8 ˚F) 1 ˚C rise in temperature, irrigation demands are projected to increase 10 percent. Transient rain-snow basins, such as those in the Western Cascade basins, are projected to be sensitive to these changes in precipitation and temperature. Cascade snowpacks are projected to be less than half of what they are today by mid-century with lower elevation snowpacks being the most vulnerable. Through the end of the 21st century, April 1 snow water equivalent is projected to decrease in the Willamette River Basin (figure 5) in two emissions scenarios - a1b (carbon intensive) or b1 (more renewables, less carbon intensive). Water demands are projected to increase throughout the 21st century, particularly in urban areas, adding an additional stress to water availability.

Other factors such as increased demand will pose an additional stressor to water availability. Water demands are projected to increase throughout the 21st century, particularly in urban areas. Part of the increased demand will likely be due to summer temperatures, and some of the demand can be attributed to overall population growth of the state. Data from Portland Water Bureau shows that there is a relationship between annual average water consumption and annual average temperature. While demand during winter months is expected to remain constant, research on urban water demand suggests that temperature is the most influential climate variable on water consumption, particularly among single family residential households. These impacts are also evident at multiple scales, including the household, neighborhood, and region.

Water quality is also likely to be impacted with rising air temperature and seasonal shifts in flow availability. Water temperatures are expected to rise as air temperature increases in the 21st century, particularly in urban streams where natural riparian vegetation is typically lacking. A decline in summer stream flow will exacerbate water temperature increases, because the low volume of water will absorb the sun's rays more than during times with larger instream flows. However, an increase in air temperature alone does not lead to major changes in stream temperature. Changes in riparian vegetation (either land use changes or climate-related) will influence streamflow and water temperature. Changes in water temperature can have significant implications for stream ecology and salmon habitat. Smaller streams in transient rain-snow basins and in eastern Oregon will be the most vulnerable to increasing summer air temperature and diminished low flows. There is little research on long term trends in water temperature in undisturbed watersheds; sites with long term data are rare. Sediment and phosphorus loads, which are a detriment to water quality, are expected to increase in winter as winter flow is projected to rise. It will be important for water resource managers statewide to include considerations for climate change in future planning.

Chapter 4 - Climate Change and Agriculture in Oregon

Oregon's agriculture has long been a part of the state's history and a backbone of the economy. The moderate, yet varied climate and fertile topsoil from glacial floods create some of the best growing conditions for a many of crops and commodities. An incredible amount of land statewide is devoted to agriculture. In 2008, Oregon had around 38,600 farms on 16.4 million acres of land. Oregon's agriculture is also of national importance; the state is the top producer of fifteen commodities. In 2008, Oregon exported $1.6 billion in agricultural commodities. The diversity of agriculture in this state creates an economic strength. That economic strength means that agriculture is especially vulnerable to climate change. Oregonians involved in agricultural practices have long been adaptable to short to long term changes in climate, though the projected rate and magnitude of increase in temperature in Oregon will exceed anything that they have faced in the past.

Agriculture is an inherently climate sensitive sector. Availability, quality and cost of water will likely be the most limiting factor for agricultural production systems under a warmer climate. Warming temperatures will lead to greater irrigation demands. For a 1.8 ˚F rise in temperature, irrigation demands are projected to increase by ten percent. Many irrigation systems in the state are fed by snowmelt and stored in reservoirs. Drought and heat waves are both costly natural disasters; even short term events can damage crop quality and reduce yields. Livestock are particularly sensitive to higher temperatures in the summer. Crops will be vulnerable to invasion by pests and diseases that thrive in a warmer climate, creating additional stress on the plant. Additionally, warmer winter temperatures will allow insects to survive over the winter or produce multiple generations within one season

Many crops have been optimized to fit a narrow temperature niche - one that may no longer be optimal under a warmer climate. The projected warming in Oregon is expected to displace current agriculture zones, with likely movements toward the coast and higher in elevation. However, much of this work is speculative - in that if a crop exists in today's climate thresholds, that a warmer climate would push them outside a suitable range. There is a need for more research on individual crops and commodities, their optimum climate, and variability thresholds for economic sustainability. Perennial crops are more vulnerable to climate variability and change than annual systems; annual crops may be easier to replace.

In Oregon, winegrapes are an excellent example of an important perennial crop that has a narrow climate range for both quality and economically sustainable production. Pinot noir is considered to be the state's marquee winegrape. It grows well in cooler climates with an average growing season temperature of 57 ˚F to 61 ˚F, such as the Willamette Valley. Prior to 1950, the Willamette Valley was in a marginal climate for growing the Pinot Noir grape (< 57 ˚F), but the warming of the past few decades have brought this region into optimal wine growing range. With continued increases in temperature that are projected through the 21st century, most of the Willamette Valley will not be viable for growing the pinot noir winegrape. Producers will have to replant a grape that grows in a different, warmer climate or to move to higher elevations or further north in latitude, both costly options.

There is evidence that points to a lengthening of the growing season worldwide. The growing season, or dates from first frost in the spring to last frost, has also lengthened across the country. In Oregon, wine regions have seen the length of the frost free period increase by 17 to 35 days. This change in growing season can have mixed benefits. On one hand, lengthening the growing season may allow for increased production. A longer growing season translates into an increased need for irrigation, though this may be mitigated somewhat by increased CO_2 fertilization.

Carbon dioxide is essential for plant growth. There are some benefits for crops with rising carbon dioxide levels. Increased CO_2 in the atmosphere may lead to increased yields and plant growth. It may also mitigate drought stress by allowing the plants to partially close their stomates, or take in less water. Negative impacts include a decline in nutritional quality and decreased efficiency of some pesticides. However, the benefits of increasing CO_2 on plants are not substantial enough to offset the negative impacts of increased greenhouse gases in the atmosphere and other climate change impacts to agriculture.

Agriculture also contributes to the climate change problem; Chapter 2 states that agriculture makes up about 9% of Oregon's greenhouse gas emissions. There are some opportunities for greenhouse gas mitigation in agriculture - including reductions of nitrous oxide and methane emissions and reduction of energy consumption.

Chapter 5 - The potential effects of climate change on Oregon's vegetation

Oregon vegetation is varied across the state and heavily influenced by the interactions of climate and topography. Given the interaction between vegetation and climate in this state, it is likely that future climate change will affect the plant species in Oregon. Currently, undeveloped areas of Western Oregon are predominantly forested and agricultural while much of Eastern Oregon is shrub/sagebrush with patches of forests, agriculture, juniper and grassland. There is clear evidence that vegetation has responded to changes in climate over the distant and recent past, with large rapid changes since the mid-1970s, coinciding with the accelerated warming of the past few decades. Understanding how vegetation has changed in the past is important for understanding how Oregon's vegetation may respond to future climate changes. Adaptive management may help in creating resiliency, but the challenge lies with the slow life cycle of many Oregon plants versus the rapid rate of warming.

Vegetation types will shift statewide as a result of a changing climate. Vegetation models show that areas of subalpine forest and tundra are projected to decrease as temperatures increase at higher elevations. Areas of shrubland in the eastern part of the state are projected to decrease. These changes in vegetation will threaten the habitat for species of management concern . An expansion of forest and woodland is projected into parts of eastern Oregon currently dominated by grassland and shrubland. On the coast, areas of mixed evergreen and subtropical mixed forest are projected to expand, marking a major transition from temperate to subtropical species (figure 7).

Wildfire will likely increase in all Oregon forest types in the coming decades. Warmer and drier summers leave forests more vulnerable to the stresses from fire danger west of the Cascades. Wildfire in forests east of the Cascades is mainly influenced by vegetation growth in the winters prior to the fire. An increase in fire activity is expected for all major forest types in the state under climate change. Large fires could become more common in Western Oregon forests (figure 8). Estimate increases in regional forest area burned ranges between 180% and 300% by the end of the century, depending on the climate scenario and estimation method examined.

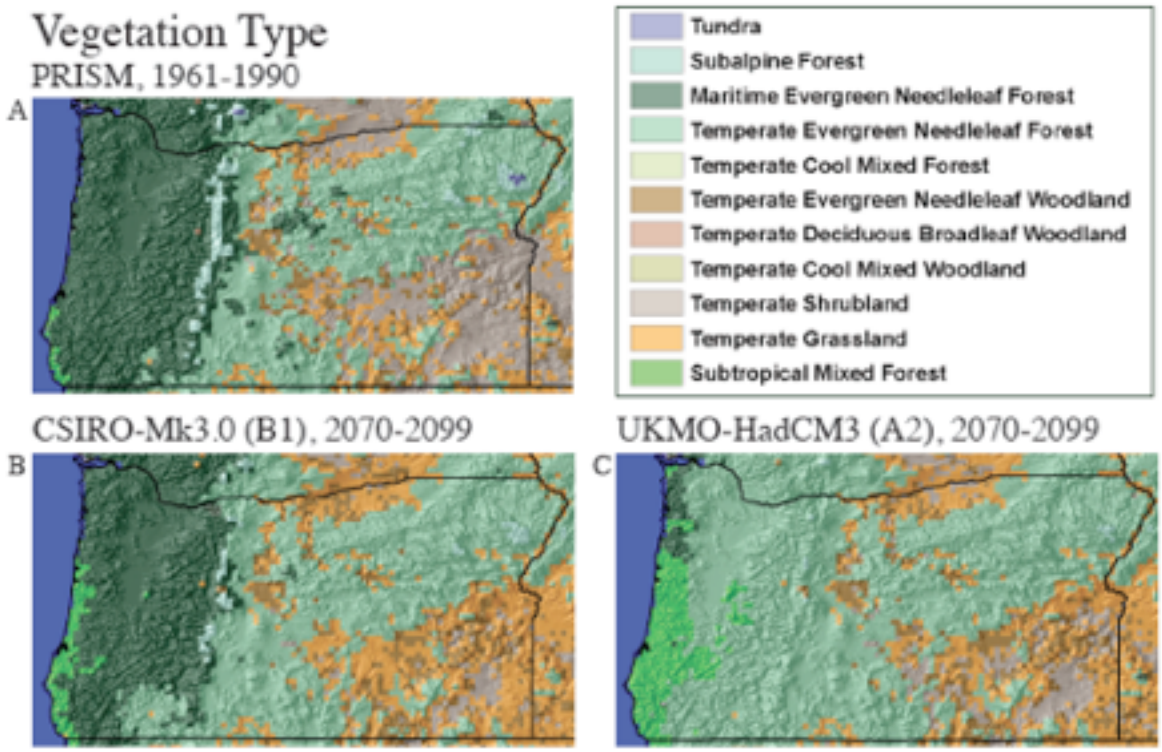

Figure 7. Vegetation types simulated by MC1 (MAPSS Group, contact: R.P. Neilson) on an 8-km grid for (A) 1961-1990 using PRISM climate data (Daly et al., 2000) and for 2070-2099 using climate data simulated (B) by CSIRO-Mk3.0 under the B1 emissions scenario and (C) by UKMO-HadCM3 under the A2 emissions scenario

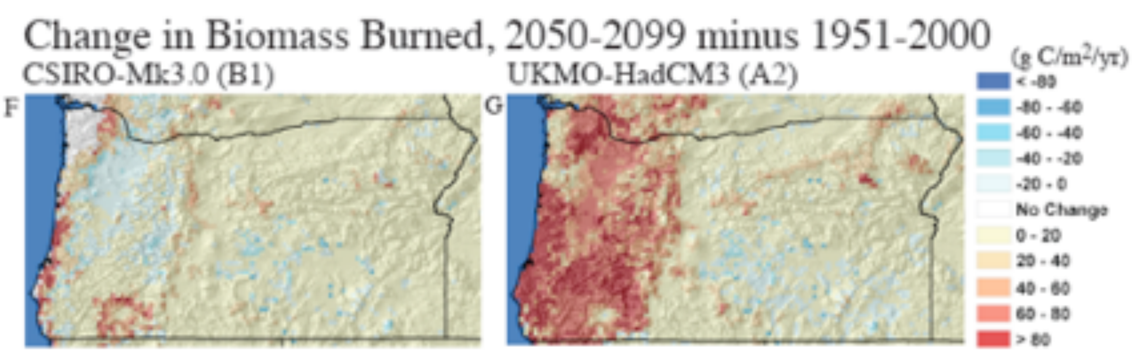

Figure 8. Future changes in biomass burned calculated as 2050-2099 values minus 1951-2000 values (F, G) were also simulated by MC1.

Pests and diseases will continue to expand northward into Oregon affecting forest species. Mountain pine beetle occurrence has been increasing over the last eight years and will likely continue to increase in a warmer climate. Drought also acts as an additional stressor in increasing vulnerability to the pest. Other pests and diseases, including sudden oak death, have been spreading northward from California into southwestern Oregon since the beginning of the century. In the case of sudden oak death, extreme precipitation events help infect more trees, which then become vulnerable to mortality during droughts. Generally, insects and diseases will expand northward in latitude, toward the coast and upward in elevation in a warming climate.

Chapter 6 - Impacts of climate change on Oregon's coasts and estuaries

The changing climate will likely have significant impacts along the coast and estuarine shorelines of Oregon. Changes associated with global climate change include rising sea levels, storminess, rising water temperatures and ocean acidification. The impacts of these changes include increased erosion, inundation of low lying areas and wetland loss and decreased estuarine water quality. Impacts from coastal erosion and flooding are already affecting the Oregon Coast (figure 9), and are an analogue for future climate change impacts. Beach elevations have been lowered as a result of extreme waves, and many beaches have seen little post-storm recovery in the intervening years. Coastal infrastructure will be under increased risk of inundation and damage under a changing climate with impacted sectors including transportation and navigation, shore protection and coastal flood structures, water supply and waste and storm water systems, and recreation, travel and hospitality.

Figure 9. Ongoing shoreline retreat over the past decade in the Rockaway cell and localized hotspot erosion effects have resulted in substantial sections of the shore having to be rip-rapped in order to safeguard property. SLR expected over the next century and enhanced storms will almost certainly increase the risk of failure of such structures and the potential loss of homes and important infrastructure backing the beach (Photo courtesy of Mr. Don Best, 2009).

Globally averaged sea level has risen through the 20th century, coincident with warming. In the Pacific Northwest, actual sea level rise varies along the coast, as a result of geologic uplift (or vertical land movement). In some spots along the coast (figure 10) The upward movement of land is exceeding actual sea level rise and have been relatively immune to sea level rise impacts thus far (blue arrow). It is nearly certain that global mean sea level will increase, by 2-4 feet (1 meter) by 2100. Coastal areas that are uplifting geologically have been relatively immune to sea level rise impacts thus far. However, by the mid 21st century, the rate of sea level rise will probably exceed vertical land movement on all stretches of the Oregon Coast. Submerged areas will experience significant erosion and flooding impacts.

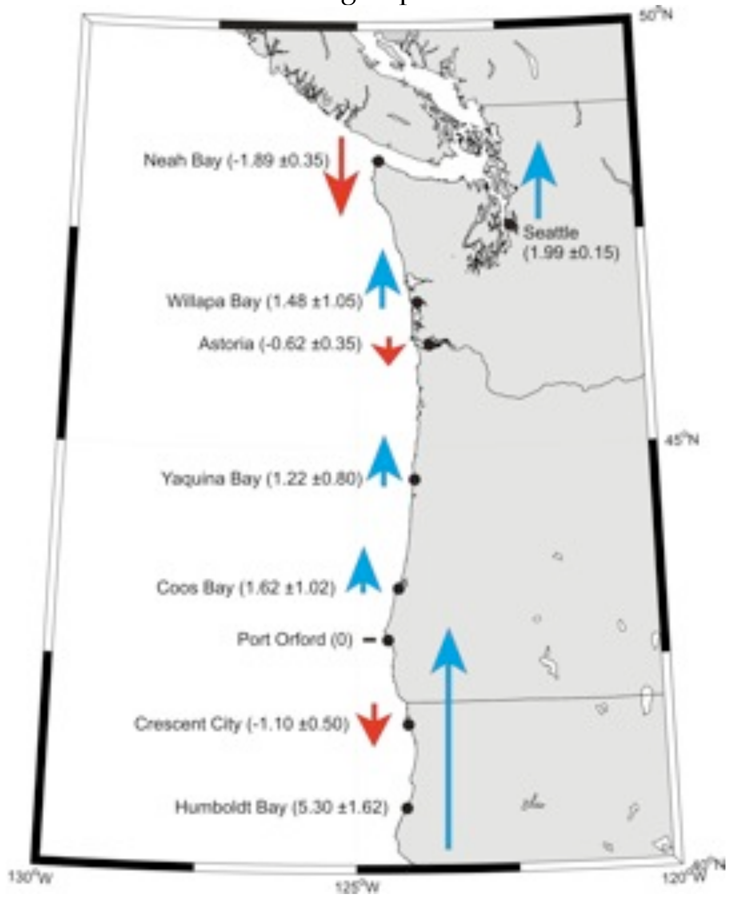

Figure 10 Analysis of NOAA tide gauges to assess changing sea levels along the coast of the PNW. Colored arrows represent the rates of change in relative sea levels (mm/yr), along with their uncertainty, generated using summer data only (see Section 6.2.2 for details). (After Komar et al., in press).

The Oregon Coast has been historically prone to severe winter storms, which are the dominant factor for flooding and erosion on the coast. Storminess has been increasing, and consequently the frequency and magnitude of these coastal flooding events will probably continue to increase. All significant wave heights measured during the winter have been increasing at a rate of 0.023 m/year, but extreme waves generated by the strongest storms are increasing at higher rates than the winter averages (0.095 m/year). The maximum has increased from about 9 meters in the late 1970s to 12 meters in 2005. This is a significant increase, though we do not yet know if this is a climate change related trend or natural variability. Therefore, we have limited ability to predict future trends in wave heights or coastal storms, but if the trend continues, impacts will be substantial. Storminess and extreme storm events have already been increasing very rapidly, leaving unarmored coastal areas vulnerable to flooding and erosion. The North Pacific winter storm track is projected to shift northward, meaning slightly fewer, but more intense storms.

The estimated long term rate of coastal wetland loss is greater for the Pacific Coast than any other areas of the US. It is likely that regional coastal climate change may result in more changes in the near-coastal and estuarine habitats. This includes changes in the intensity and timing of coastal upwelling, increased fog and onshore winds, shifts in temperatures and chemistry of nearshore waters. The combination of these climate and nearshore ocean changes will exert stress on the communities of near-coastal and estuarine organisms. The range of species responses to the climate change stressors may include elevational shifts in the distribution of submerged aquatic vegetation, disruption of shell formation for calcifying organisms, alteration of the phenology of phytoplankton blooms, shoreward migration of tidal marshes, and increased colonization by non-indigenous aquatic species.

Chapter 7 - Oregon's fish and wildlife in a changing climate

Oregon's fish and wildlife include animals on land, fish and other species in rivers and lakes, and various kinds of sea life in estuaries and coastal ocean. Oregon is one of the most ecologically diverse states in the country. The state's robust biodiversity, some of which is already threatened or endangered -- inhabits complex and dynamic ecosystems that we have only begun to understand, let alone examine in terms of climate change.It is clear that the abundance and distribution of species are shifting already and will shift more rapidly as habitats on land, in freshwater, and in the sea are altered due to increasing temperatures and related environmental changes. It remains to be seen if past changes are all tied to global climate change or if they are a result of some other variability, but they represent a proxy for how species may shift in a warmer climate.

Among the observed species changes: Insects are moving in from the south of Oregon, frogs are reproducing earlier in the year and land birds are shifting their distributions northward and migrating earlier. Freshwater fish are losing their cool-water habitats. In the marine environment, algal blooms have increased (figure 11) and the highly predatory Humboldt squid have shifted their distribution from subtropical and tropical regions, making an appearance off the coast of Oregon in the last few years.

In a warmer climate, plant and animal species may have to shift upward or northward on land or deeper at sea for survival. Rare or endangered species may become less abundant or extinct; insect pests, invasive species and harmful algal blooms may become more abundant. Declines in the abundance of species may be caused directly by physiological stress related to changes in temperature, water availability, and other environmental shifts, and/or indirectly by habitat degradation and negative interactions with species that are benefited by climate change (diseases, parasites, predators, and competitors).

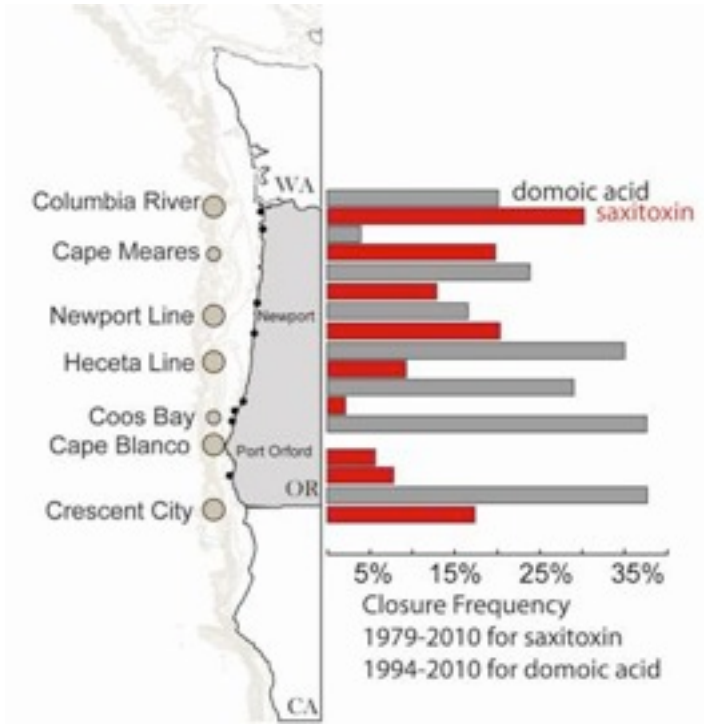

Figure 11 Left: Current sites in the Oregon surf zone (dots) and offshore sampling lines (circles) sampled for harmful algal blooms relative to ocean depth contours (gray lines). Regions near the Columbia River outflow, Heceta Bank and Cape Blanco are sites of strong summer phytoplankton blooms. Right: The percentage of positive samples exceeding shellfish fishery closure limits are shown as bars for domoic acid (grey) and saxitoxin (red) at different latitudes along the coast

Understanding the responses of Oregon's fish and wildlife to climate change will require a better understanding of smaller organisms and insects and ocean species. Knowledge of ecological interactions will be crucial for understanding the related effects of climate change (increased predation or competition, for example). Management and natural resource polices that protect intact ecosystems are a tool for adaptation; native species can live and migrate to these safe refugia.

Chapter 8 - Toward assessing the economic impacts of climate change on Oregon

Oregon's economy, like many other states, is likely to be affected by a changing climate and by policies addressing projected changes. There is still much work to be done in developing a complete assessment on the economic impacts of climate change in Oregon. The work to date suggests that climate change poses economic risks to the state. The magnitude of the impact will depend on the rate of physical change, the willingness of humans to alter their behaviors, and the resilience of our ecosystems. It is not possible, at this time, to provide a comprehensive economic assessment of the impacts of climate change in this state.

Quantifying the economic impacts of the previously discussed sectors in this report requires models that predict behaviors as well as changes in climate variables and changes in economic variables. Some studies utilize a business as usual scenario - in that society and behaviors continue in the same manner and people do not take steps to mitigate greenhouse gases, adapt to climate change or different economic scenarios.

The magnitude of economic impact is dependent on the magnitude and rate of future climate and economic changes. There are projects in place at Oregon State University and other institutions that are examining how agricultural sectors may fare under a cap and trade or other incentive based policies. Quantifying the cost of inaction is controversial because it requires a connection between changes in climate and human responses. Many models suggest that the costs of inaction in climate change would be 2% of the world's gross domestic product (GDP), but the Stern study in 2006 suggests the costs could be substantially greater (5-20% of world GDP).

Agriculture is one of the most important sectors of the state's economy and is highly sensitive to climate. Farms and ranches are the largest group of owners and managers of land impacting ecosystem services, such as greenhouse gas mitigation, water quality and quantity regulation, and wildlife habitat and biodiversity conservation. Consequently, the impacts of climate change on agriculture, the impact of policies designed to reduce greenhouse gas emissions, and agriculture's ability to adapt to and mitigate the impacts of climate change are critical issues for to consider. Water availability will be the primary factor in agricultural production in the future. Both California and Washington projected negative economic impacts with the loss of irrigated water by the end of the century. Oregon could experience similar impacts if water for irrigation becomes scarce, but additional research is required to quantify the economic impact of climate change on water availability for irrigation.

Climate change will have multiple and sometimes conflicting impacts on Oregon's economy. There is still much uncertainty of the full economic impacts of climate change. An understanding of physical climate impacts and improvements in measuring and valuing economic change continues to evolve. Climate change projections tend to be at a spatial scale that is too large to be relevant for smaller systems, like the agricultural sector. Research should continue in quantifying the costs and benefits of action: both adaptation and mitigation.

Chapter 9 - Human dimensions of climate change: public knowledge, attitudes, and barriers to change; impacts on cultural and built environment; and potential public health impacts

This report discusses the impacts of climate change on land and in the ocean in significant detail, but it offers much less insight on the human dimensions of climate change, beyond the anthropogenic contribution to the problem. Undoubtedly, climate change will impact Oregonians directly. Climate change in Oregon will likely have an impact on our built environment - that is, things that are man-made (roads, airports, infrastructure) - and on public health. The attitudes of Oregonians toward climate change are somewhat unknown, but small-scale surveys indicate that many residents of our state would consider it a problem worth attention by policymakers.

Also, very little Oregon-specific research on the impacts of climate change on public, or human health have been performed. This does not mean that the state is immune to an increase or emergence of vector-borne diseases that harm humans in a warming climate, but rather that specific research needs to be performed on specific diseases using regional climate projections for Oregon. Disease is discussed in Agriculture (chapter 4), Vegetation (chapter 5) and Fish and Wildlife (chapter 7). It can be speculated that human disease will also act in a manner similar to those that impact both plant and other animals, but there is room for more research in this area.

There have been a few small studies that survey groups understanding of climate change and general acceptance of the problem. A study of more than 1500 Oregon households about the role of renewable energy revealed that almost two-thirds view climate change as a moderate or serious problem requiring policy changes regarding renewable energy. These initial and small-scale studies suggest that Oregonians know something about climate change and many are likely to perceive it as a problem although they may not know all the scientific details. There are barriers needing to be addressed if expect individuals or groups to change behaviors for either mitigating or adapting to climate change, although there appears to be general acceptance of, and desire for, government policies to direct such behavioral change.

There may be impacts to areas of cultural importance to Oregonians. Native tribes may be vulnerable to climate change, with the potential loss of iconic species or shifts in ecosystems that are a significant part of their culture. Coastal tribes risk inundation and loss from impacts to Oregon's coastline. All Oregonians face impacts to areas of cultural value, such as two important Oregon icons - Mt. Hood and Crater Lake. Aside from aesthetics with potential snowpack loss, climate may change species and forest composition.