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The Economic Costs of Climate Change for Oregonians: A First Look

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Executive Summary

By increasing the frequency and intensity of heatwaves, wildfires, droughts, flooding and other impacts, climate change imposes costs on Oregon's economy every year, on every Oregonian. We present a review of public data and research results to provide an initial, partial assessment of these costs both today and into the future.

A few examples of costs include (all numbers in 2023 dollars):

- The economic costs to Oregonians from heat-related deaths during the 2021 heatwave total between $1.3 billion and $4.6 billion.
- Including both short-term and long-term costs, Oregon's 2018 fire season may have generated $6.8 billion in costs, or $3,900 per household. Future fire seasons may generate higher or lower costs.
- The average Oregonian could lose roughly $12,000 in personal income per year due to changes in the climate that have already been set in motion due to past greenhouse gas emissions. Oregonians will also likely see increases in the cost of food and other goods and services.
- Oregonians risk losing over $450 million in ecosystem services each year from salt marshes depending on the degree of sea level rise.
- Douglas fir die-off (traced clearly to climate change) in southern Oregon is eliminating carbon sequestration services worth over $100 million per year.
- Current global analyses of the impacts of climate change over the next several decades, if applied to Oregon, suggest that climate change may reduce Oregon's gross domestic product by $7,500 per Oregonian per year.

These costs can be both direct (e.g. an increased risk of a house burning down in a wildfire) and indirect (e.g. an increase in home insurance premiums due to increases in wildfire risk). Some are directly observable through market prices, meaning they materialize as decreases in cash available for use on other things or increases in the amount of spending necessary to avoid harm. Others are "non-market" values, meaning that they do not have an immediate cash effect but represent a reduction in quality of life or economic well-being in ways that are quantifiable in dollar terms. Some of these costs are inclusive of each other: that is, it is not appropriate to sum all of these costs to obtain a single overall cost.

In short: the effects of climate change are already impacting Oregonians' economic bottom lines and reducing their overall economic well-being. These impacts will grow in the future without significant investments in prevention, mitigation, and adaptation.

The science is undeniable: Every day, carbon dioxide and other pollutants in the atmosphere cause changes in climate that damage the economic well-being of workers, families, businesses, and communities in Oregon and around the globe.

Introduction

The science is undeniable: Every day, carbon dioxide and other pollutants in the atmosphere cause changes in climate that damage the economic well-being of workers, families, businesses, and communities in Oregon and around the globe. The damage comes via many pathways. Heatwaves, storms, floods, and other extreme weather events injure and kill people, livestock, and wildlife; they damage private property and public infrastructure; and they force communities to devote additional time and resources to provide emergency services. Changes in temperature and precipitation reduce crop production, diminish labor productivity, and force families, businesses, hospitals, and other entities to pay more to cool their buildings. Rising sea levels expose coastal communities to damage from waves and threaten to submerge valuable habitats like salt marshes. Climate change disrupts industrial supply chains and reduces productivity and the quality of life locally, nationally, and globally. Indeed, statewide focus groups conducted by the University of Oregon's Institute for Policy Research and Engagement identified more than two dozen potential damages or harms that climate change may impose on Oregonians (Institute for Policy Research and Engagement, 2024).

That said, much of the analysis about the costs imposed by climate change is conducted at a national or international scale and considers time periods that extend to centuries (IPCC, 2023). While these studies are useful in understanding the complexities of economic damages from climate change, they provide little local insight or guidance: it can be difficult for us as Oregonians to connect to astronomical dollar amounts. In this report, we take a local, near-term perspective. We describe the costs that climate change is imposing or will impose on Oregonians today and over the next couple of decades. We call this report a "first look" at these costs because it is an integration of results from existing research here in Oregon and elsewhere to make reasonable estimates of some of these costs, rather than a construction of novel estimates from the bottom up.

In this report, we focus on some of the most visible effects of climate change: heat and human health, wildfires, water resources, and ecosystems. We report on recent efforts to understand how the changing climate will affect the global economy (and therefore Oregon's economy). We are not alone in focusing on Oregon; we aim to complement other projects by providing numbers around which discussions can be shaped (Fleishman, 2023). For example, Oregon's Sixth Climate Assessment described a wide range of channels through which Oregonians may incur costs, including heat, wildfires, water scarcity, degraded ecosystems, loss of timberland, declining snowpack, and reductions in gross domestic product (Dundas et al., 2023). State agencies are also working to quantify the costs of climate change relevant to their portfolios (ODOT, 2012).

The numbers reported here are substantial: thousands of dollars per year per Oregon household and billions of dollars per year for the state as whole.

Understanding these costs is important for several reasons. First, and most importantly, the effects of climate change aren't set in stone: action now to mitigate and adapt to climate change will almost certainly improve our well-being in the future. However, those actions come at a cost in the present day. Without the best available information to understand the future benefits created by mitigation and adaptation, it is impossible to undertake the kinds of "cost-benefit" analyses that drive public and private decision making.

Furthermore, understanding future harms generated by climate change lays the basis for cost-recovery options. Actors within our legal, regulatory, and political systems (in Oregon, in other states, and at the federal level) are working to assign responsibility for paying the costs imposed by climate change. However, assigning that responsibility is almost impossible without having some idea of the magnitude of those costs.

The numbers reported here are substantial: thousands of dollars per year per Oregon household and billions of dollars per year for the state as whole. Some of these costs are inclusive of each other: that is, it is not appropriate to sum all these costs to obtain a single overall cost. We also note that since we are combining estimates from different scientific reports published in different years, we have used the Consumer Price Index, a measure of inflation, to convert all dollar amounts to 2023 dollars. A spreadsheet detailing the calculations behind the numbers we report is available on our website: https://www.oregonforce.org/. We hope that these numbers help provide the basis for policy action at the local and state levels to reduce greenhouse gas emissions and to mitigate the risks that the existing pollution is already creating for Oregonians every day.

Finally, the numbers contained within this report are estimates we have translated, adopted, and/or applied to Oregon using assumptions which we believe are reasonable given our present understanding. There is a considerable amount of uncertainty about the future climate in Oregon and the impacts that changes in the climate (both locally and more broadly) will have on Oregon's economy. Different researchers and analysts may reasonably apply different assumptions and calculate costs which may be higher or lower than those we present here. Indeed, we expect that our own estimates of costs will change as more data becomes available and as the scientific understanding of climate change improves with additional research.

About FORCE

The Forum on Oregon Climate Economics (FORCE) seeks to inform policy interventions and public discourse with rigorous economic data. We are a team of economic researchers and practitioners with deep experience of both the economics of the natural environment and the work involved in translating research into policy practice. It's important to note up front that while climate policy is often highly politicized, FORCE is non-partisan and our reports are focused on providing information, not performing advocacy.

How Economists Think About Costs

Economists talk about costs a lot, and we are no exception. But before we go any further, we want to be clear about what we mean when we talk about costs and introduce a couple of core concepts for understanding the way that economists and other policy experts think about climate change and related issues.

COSTS

Most of the time, when we hear "cost" we think in terms of money, like the price of buying food at the grocery store or paying a utility bill. However, economists take a broader view. When we say "cost," what we really mean is "anything we have to give up to get something else." This not only includes money, but also non-monetary resources, such as time and opportunities. For ease of discussion, economists often group these into three kinds of costs: direct, indirect, and opportunity costs.

DIRECT COSTS

These are the most obvious, "out-of-pocket" expenses. If you are a small business owner using a spreadsheet to keep track of your revenues and expenses, each dollar that you spend on your business is a direct cost. For example, if a bakery invests in new air conditioning to give its workers a break from the heat, the direct costs include the money spent on purchasing and installing the new units.

INDIRECT COSTS

These costs are often harder to see but just as important. They can include both impacts on economic activity that aren't recorded through a market transaction and downstream impacts of a decision that aren't considered at the time a decision is made. For example, if a city builds a new water treatment facility to handle increasing stormwater runoff, indirect costs could include environmental damage caused by construction, and the costs of removing an older facility once its replacement is completed.

OPPORTUNITY COSTS

This is a key concept in economics. Opportunity costs refer to the other choices that we give up when we make any choice. If a city spends money on a new water treatment facility, that money can't be used for something else, like improving schools or building a new bridge. The opportunity cost of any choice is the value of the next best alternative that was forgone.

MARKET VERSUS NON-MARKET VALUES

Not everything that people value can be easily bought or sold in a marketplace. While apples, babysitters, and health insurance plans have clear price tags attached, other things we value don't. For example, there is no clear price tag that we can place on time spent with our loved ones, fishing for steelhead, or simply taking a walk on a trail in the woods. Costs and benefits in the former category are often referred to as market values because of their visibility in the marketplace, while costs and benefits in the latter category are often referred to as non-market values.

While it might be easy to list some of the costs and benefits in each category for different choices, it is considerably harder to compare them and create a measure of total economic value. Economists have devised several methods for measuring non-market costs and benefits.

RISK AND EXPECTED VALUE

Many of the threats posed by climate change are uncertain. It is impossible to say for certain that a particular house will burn down in a wildfire, or that a reservoir will dry up during a severe drought. Instead, these events are risks: they are things that may occur and the probability of that occurrence may be measurable.

Economists and others use the concept of "expected value" to help understand the costs of various risks.

To calculate an expected value of an uncertain outcome, analysts simply multiply the probability of each possible outcome by the cost incurred by that outcome.

For example, suppose each year there is an 80% chance of having a mild fire season, and a 20% chance of a severe fire season. Suppose (for the sake of a simple mathematical exercise) mild fire seasons destroy 100 homes, and severe fire seasons destroy 2,000 homes. The expected value of the number of homes destroyed per year by fire is (80% * 100 + 20% * 2,000), or 480 homes.

COUNTERFACTUALS

Another key tool in the proverbial belt of any economist is the "counterfactual." Essentially, we ask "what would have happened if things had been different?"

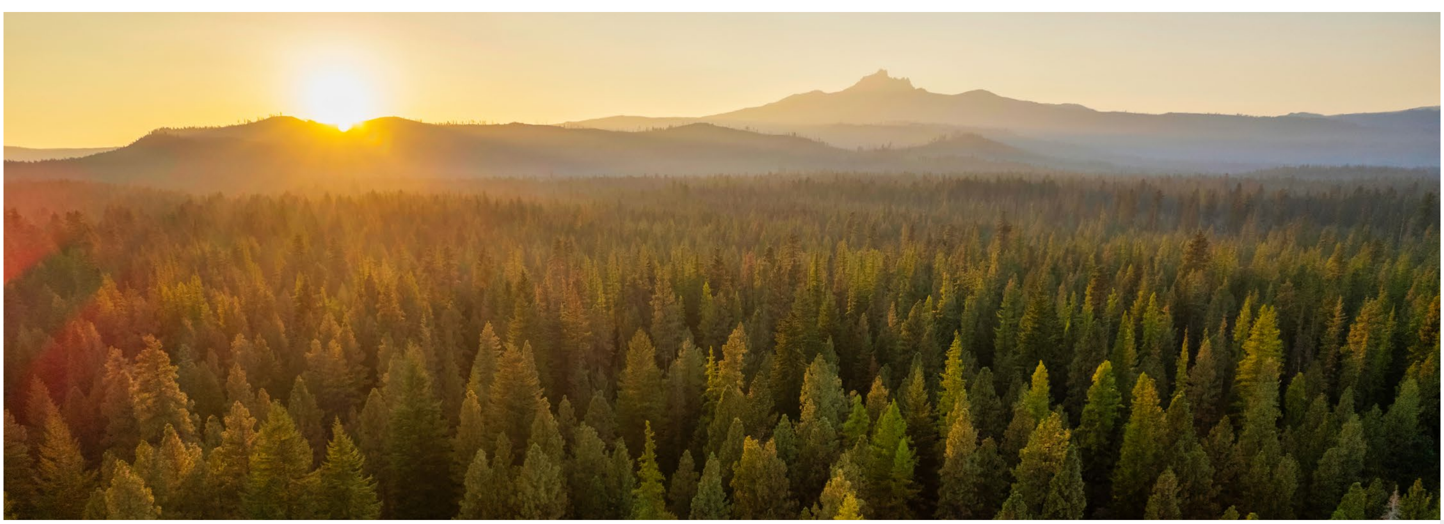
A counterfactual is like an alternate reality: it's the situation that would have occurred if the decision or event in question hadn't happened. By comparing the real world to this hypothetical scenario, economists can often calculate the costs and benefits of various decisions.

For example, suppose the government introduces a new policy to reduce carbon emissions. To evaluate the effectiveness of this policy, economists would try to understand what emissions would probably have looked like if the policy had never been introduced. This hypothetical scenario is the counterfactual. By comparing actual emissions measured while the policy was in effect to the counterfactual emissions, economists can estimate the impact of the policy. Requirements to use this "with and without" framework are often explicit in laws, rules and regulations governing public policy choices. For example, this was the approach used to assess benefits and costs from the 1990 U.S. Clean Air Act Amendments (U.S. Environmental Protection Agency, 2011).

Counterfactuals aren't unique to economic analysis. For example, pharmaceutical studies conduct randomized controlled trials to evaluate new medications. The clinical outcomes of the group that receive the new medication (the "experimental group") are compared against the outcomes of those that don't receive the medication (the "control group") to measure the effectiveness of the new drug. In other words, the experiences of the control group serve as a counterfactual: they represent what the experimental group would likely have experienced if they hadn't been given the new medication.

BRINGING IT ALL TOGETHER

The costs of climate change are complex and involve both direct, indirect, and opportunity costs with both market and non-market values. To understand these costs, nearly all analyses (including those we discuss in this report) create a "counterfactual:" what would the world look like if climate change wasn't happening? Generally, researchers create this counterfactual by considering the state of the environment many years ago before global carbon emissions reached a certain threshold. They then consider other factors that have changed in that time such as technology, education, and labor markets to construct the most plausible counterfactual possible. By comparing our current reality to this hypothetical scenario, analysts can estimate the extra costs we're facing due to climate change.



Some Economic Costs of Climate Change on Oregonians

Heat and Human Health

Oregon features a highly diversified natural environment shaped by the state's geography, ranging from the Pacific coastline to the Cascade Mountains and the high desert of the interior. Western Oregon, including the Willamette Valley and coastal areas, experiences a temperate maritime climate with mild wet winters and dry summers. In contrast, Eastern Oregon has a more arid, continental climate, characterized by colder winters, hotter summers, and less moisture overall.

Heatwaves are a natural part of Oregon's climate (Fleishman, 2023). However, as global temperatures rise, Oregon is projected to see increasing average temperatures across the state, with more frequent heatwaves and higher summer temperatures. Fleishman (2023, p. 7) report that "Oregon's annual average temperature increased by about 2.2°F per century since 1895. If greenhouse gas emissions continue at current levels, annual temperature in Oregon is projected to increase by 5°F by the 2050s and 8.2°F by the 2080s, with the greatest seasonal increases in summer." These rising temperatures will exacerbate drought conditions, particularly in Eastern Oregon, reduce agricultural productivity, and increase the frequency of wildfires, which we discuss in more detail below.

We begin with heatwaves, however, because they have received much attention in Oregon since the unprecedented heatwave experienced throughout the Pacific Northwest in late June and early July of 2021 (White et al., 2023). Heatwaves kill by overwhelming the body's ability to regulate its internal temperature. Even otherwise-healthy individuals can be permanently injured or killed if their core temperature rises above 104 degrees for an extended period.

After the 2021 heatwave, the Oregon Health Authority reviewed local records and concluded that heat during the event was the sole cause of death for 102 Oregonians (Oregon Health Authority, 2023). Calculating the economic costs of these deaths is fraught, to say the least. Yet, we implement life-saving policies all the time, and often with clear economic rationale aimed at weighing costs and benefits where lives are at stake. A widely-used approach is based on the value of a statistical life (VSL), which reflects an individual's willingness to pay to prevent a fatality (U.S. Consumer Product Safety Commission, 2024, p. 27740). U.S. federal agencies, including the U.S. Environmental Protection Agency, the U.S. Department of Transportation, and the U.S. Department of Health and Human Services use a VSL for regulatory analyses. The U.S. Consumer Product Safety Commission (CPSC) recently adopted a VSL of $13 million (in 2023 dollars) for adults and $26 million for children (U.S. Consumer Product Safety Commission, 2024). The VSL figures used by government agencies are quite similar, but we use the CPSC values because they are based on a detailed review of recent VSL studies and have recently gone through an agency review and public comment process.

These numbers indicate that the economic costs to Oregonians from heat-related deaths during the 2021 heatwave are at least $1.3 billion dollars (in 2023 dollars).

That said, heat-related deaths are among the most difficult to measure, as heatwaves kill not just through the acute effects of heatstroke, but also exacerbate other health conditions that can lead to death in the days and weeks after the heatwave is over. Even deaths occurring during the heatwave may be misattributed to other causes. Consequently, many epidemiologists believe that most reports undercount the death toll from heatwaves (Schiffman, 2024) – thus the caveat that Oregon's official numbers refer only to deaths with heat as the "sole cause." An analysis of "excess mortality" conducted by researchers in Washington state (see sidebar) suggests that the true death toll stemming from the 2021 heatwave is 250% higher than the "sole cause" estimates (Climate Impacts Group, 2023), in which case the total cost would be $4.6 billion.

Notably, these estimates capture only mortality and do not include the impact of heatwaves on morbidity, or the overall level of physical and mental health in a population. Heatwaves have been found to increase both mortality and morbidity (Arsad et al., 2022; Song et al., 2017; Ye et al., 2012).

Excess Mortality: An Application of Counterfactuals

The phrase "excess mortality" entered the public lexicon as policymakers tried to grapple with COVID-19. The phrase refers to a technique used by epidemiologists and other researchers to understand the impacts of events or policies on mortality, especially when such things can't be linked directly to a cause of death (coroners generally don't write "legislation" on death certificates).

These studies use statistical analysis and expected values to construct a counterfactual number of deaths that likely would have occurred in the absence of the event or policy. For example, an analyst might examine many years of data and estimate that a particular city could expect to experience 100 deaths during a given week. If instead, the city had a heatwave during that week and experienced 150 deaths, the excess mortality is 50 deaths. Those deaths can be attributed to the heatwave as they likely would not have occurred in the absence of the event.

Wildfires

Wildfires play important roles in sustaining healthy ecosystems in Oregon — forests, grasslands, and shrublands. But climate change-induced increases in wildfire frequency and severity can be harmful to these ecosystems and certainly to Oregonians. Several factors contribute to the increases. The growth of housing and other development into wildlands raises the probability that human activities will ignite fires that spread into the wildlands and, conversely, the probability that a wildland fire will destroy homes and communities. Non-native vegetation, such as some highly flammable grasses, can increase fire risks, as can industrial practices that create plantations of closely packed young trees that can burn hotter and move faster than fires in older trees (Zald & Dunn, 2018). Taking several of these factors into consideration, the USDA Forest Service has published detailed maps of where wildfire risk in Oregon is the greatest (Figure 1).

Changes in climate magnify these and other risk factors. Most important, these changes raise daily temperatures and lengthen the summer fire season, the period of consecutive hot, dry days between the last rains of spring and the first rains of autumn. The result: more fires because vegetation catches fire more easily and bigger fires because, once lit, vegetation burns hotter and faster.

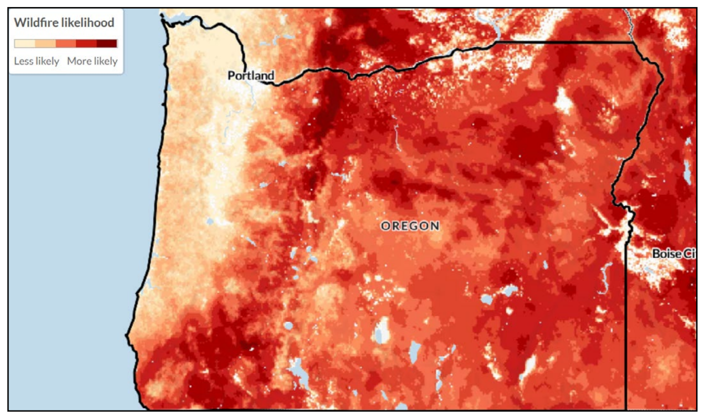


Figure 1: Wildfire Risk to Oregonians. Source: USDA Forest Service. 2024.

These shifts impose serious economic costs on all Oregonians. Many costs occur immediately, through damage to homes and property, losses of merchantable timber, health impacts on humans, and the fire-suppression activities of agencies and property owners. Additional costs occur over time, as local businesses, workers, and communities experience a long-term economic downturn in the years following the fire; and Oregonians statewide each year see more of their tax dollars spent responding to fires rather than on schools, housing, and other public services (Oregon Department of Forestry, 2023).

Wildfire costs vary greatly, depending on where and when fires occur, on their severity and duration, and on what burns: houses, businesses, infrastructure, timber, etc. The costs incurred to suppress fires receives a lot of attention; the federal government spent over $500 million on fire suppression efforts in Oregon in 2018 (Bureau of Land Management and USDA Forest Service, 2019), which translates to roughly $620 million in 2023 dollars. However, research examining wildfires across western states shows that suppression efforts represent only about 9 percent of the total short-term and long-term costs incurred by individuals, local communities, and governments (Headwaters Economics, 2018). Other costs include immediate damage to property, aid and evacuation, loss of property value, infrastructure repair, and long-term loss of services from degraded ecosystems. Using this ratio, the total costs of Oregon's 2018 wildfire season in today's dollars was more than $6.8 billion, or $3,900 per household.

Wildfire costs vary greatly, depending on where and when fires occur, on their severity and duration, and on what burns: houses, businesses, infrastructure, timber, etc.

As fire seasons vary from year to year, the costs incurred in each season will vary as well. However, climate change is expected to increase both the duration and severity of the wildfire season each year. While estimates differ, it is not unreasonable to expect fire activity in the Cascades and the Coast Range to double in the decades to come (Dye et al., 2024, Table 2).

It's important to note that these numbers exclude some indirect costs, such as increases in home insurance premiums, and some direct costs which are harder to measure, such as the amounts homeowners and communities spend to reduce fire risks. Estimates of these costs are yet unavailable.

2020's "Labor Day" Wildfires

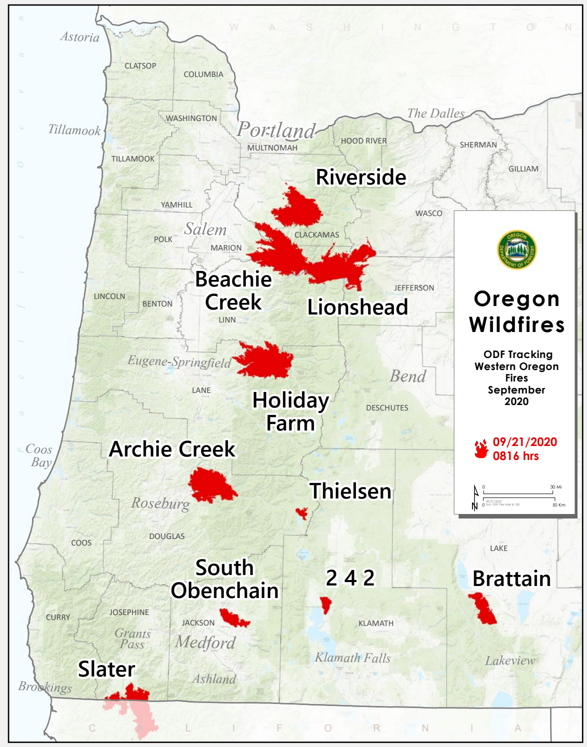


Figure 2: Labor Day wildfires, 2020.

Many Oregonians have vivid memories of 2020's wildfires, especially in September. With vegetation dried by a hot summer and historic winds blowing from the east, the fires burned more than 1.2 million acres of land, destroyed more than 5,000 homes including the communities of Finn Rock, Nimrod, and Blue River. Nine people were killed.

Researchers at Oregon State University have concluded that the likelihood of extreme autumn fire conditions, such as those experienced in September 2020, has increased 40% in recent years, due to human-caused changes in climate (Dye et al., 2024).

Air Quality

Air quality in the western United States has deteriorated in recent years with more deterioration expected in the future (Fleishman, 2023, pp. 112–113). Much of the worsening of Oregon's air quality stems from changes in climate that result in increases in wildfires and exposure to wildfire smoke.

Wildfire smoke imposes economic costs on Oregonians via several pathways. One involves the harmful impacts on human health from several pollutants in the smoke: fine particulate matter, called PM2.5, volatile organic compounds, and ozone (smog). PM2.5 causes special concern. These include increasing the severity of asthma and chronic pulmonary disease, and–especially for seniors–raising the risk of heart disease, heart failure, and dementia. Exposure to PM2.5 in wildfire smoke can have other harmful health effects. Exposure during pregnancy and early childhood can increase the incidence of preterm birth, low birth weight, and infant mortality. It also can reduce the lifelong earnings of young people by impairing cognitive development (Feng et al., 2016).

According to an "excess mortality" analysis conducted by researchers at Stanford University and elsewhere, wildfire smoke was responsible for an average of 411 deaths in Oregon per year over the past decade (Qiu et al., 2024, Table S7). That analysis predicts that under our planet's current trajectory, the number of deaths will increase by around 600 per year by the 2050s under a moderate warming scenario. Again, using the estimated economic cost of mortality of $13 million, the mortality costs of wildfire smoke in Oregon will grow by over $7.9 billion dollars per year, or by $4,500 per household relative to today.

Wildfire smoke imposes economic costs on Oregonians via several pathways.

Wildfire smoke also reduces certain workers' earnings, primarily by curtailing the number of hours working outdoors. At the current minimum wages in Oregon, a worker unable to work because of smoke would lose about $110-$120 per day in gross earnings. Insofar as they are overrepresented in the outdoor workforce, Hispanic and low-income individuals likely would bear the bulk of these costs. No credible estimate of the statewide total lost earnings is currently available.

Wildfire smoke imposes other costs on Oregon households. When smoke is so intense that children don't go to school, parents stay home to care for them and don't go to work. Many don't go to work so they can tend to elderly parents made ill by the smoke. Families buy air purifiers to help clean the air in their homes. People dislike the smell and the reduced visibility and the disruption to daily routines. One study found that these and related costs total about $190 per adult per day of exposure to wildfire smoke (Jones, 2018). Using the average household size in Oregon, it is reasonable to conclude that the economic cost of wildfire smoke is around $450 per household per day.

Fresh Water

Climate change is already affecting Oregon's water resources and will continue to do so into the future. While precipitation patterns vary across the state, one relative constant is the seasonal cyclicality of Oregon's water cycle. Most precipitation falls in the winter months, some in the spring and fall, and very little in the summer. Mountain snowpack acts as a reservoir of water which accumulates throughout the winter months and is slowly drawn down over the warmer months in the form of snowmelt; much of the moisture available to the state in the summer months comes from this melting snow (with underground aquifers comprising another portion).

This pattern means that Oregon's water supply has multiple vulnerabilities. First, the winter snowpack accumulation may be smaller than normal due to either warmer-than-average conditions (limiting the rate at which precipitation is transformed into snowpack) or drier-than-average conditions (limiting the available precipitation to feed the snowpack). Second, the rate of snowmelt in the spring and summer is determined by temperature and cloud cover. A spring season featuring warmer temperatures and sunnier conditions will draw down the snowpack more quickly than a cooler and cloudier spring, leaving less water available for ecosystem services, agricultural irrigation, and other human uses in the summer.

This pattern may help explain the sometimes contradictory and confusing information that has circulated about Oregon's future water resources under a changing climate. While global climate models generally predict an increase in the average total precipitation falling in Oregon (Almazroui et al., 2021), these predictions generally come with warmer temperatures throughout the year, and a decrease in precipitation in the summer (Rupp et al., 2017). This means a decrease in the size of the snowpack, particularly at lower elevations (Sproles et al., 2013), and an increase in the frequency and severity of drought conditions across most of Oregon (Gu et al., 2020; Jung & Chang, 2012).

About 85% of the water diverted from Oregon's rivers and aquifers is used for agricultural irrigation (Oregon Water Resources Department, 2015). Thus, the largest impact of drought is on agricultural production, which contributes roughly $5.7 billion per year directly to Oregon's economy, or roughly $3,200 per Oregon household per year (Oregon State Board of Agriculture, 2021). Though drought conditions are broadly known to reduce agricultural production, there are no specific estimates available for the impact of drought conditions on agricultural output in Oregon. The remaining water diversion is largely used for municipal water demand, including household drinking water and industrial and commercial demand that is served by municipal water systems. The Water Resources Department projects that this demand will increase approximately 20% by 2050, primarily due to population growth, putting further strain on Oregon's water availability (Oregon Water Resources Department, 2015).

Climate change also threatens water quality, which can be assessed along multiple dimensions including physical parameters (such as temperature and turbidity), chemical parameters (such as dissolved oxygen and nutrients), and biological parameters (such as E. coli). In 2022, over 60% of Oregon's coastal waters were categorized by the U.S. Environmental Protection Agency as impaired due to bacteria and other microbes; over 75% of lakes and reservoirs were classified as impaired primarily due to algae; and over 62% of rivers and streams were classified as impaired primarily due to bacteria and other microbes (US EPA, 2021).

Climate change is expected to increase water temperatures throughout the state, which in turn increases bacterial growth. This increases the cost of providing safe drinking water as towns and cities must spend more to treat municipal water systems (Chang et al., 2021). Poor water quality including bacterial concentration has been shown to negatively affect property sale prices in Oregon (Netusil et al., 2014).

Ocean Acidification and Warming

Climate change has the potential to disrupt ocean and coastal ecosystems on a scale that is difficult to grasp, with large economic costs for all Oregonians. There are two interrelated processes at work: ocean acidification and ocean warming, which are commonly referred to collectively as OAW.

Acidification occurs as the absorption of atmospheric CO_2 triggers a series of chemical reactions that increase the acidity and decrease the concentration of carbonate ions in the water. So far, absorption of CO_2 has increased acidity of surface waters by about 30% and, if current trends in atmospheric CO_2 continue, by 2100 these waters could be “nearly 150 percent more acidic, resulting in a pH that the oceans haven’t experienced for more than 20 million years”(NOAA Fisheries, 2023). Among the dire predictions associated with acidification include dramatic reductions in populations of some calcifying species, including oysters, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton – the latter effect putting the entire marine food chain at risk.

The second process is ocean warming. The mechanisms of ocean warming are complex, and include heat transfer from the atmosphere, downwelling infrared radiation, stratification, reductions in mixing, changes in ocean currents, and changes in cloud cover patterns (Hoegh-Guldberg et al., 2014). Global average sea surface temperature (SST) has risen by over 2.5 °F

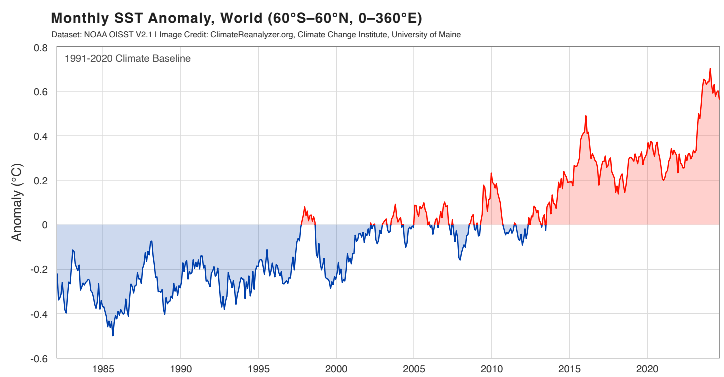


Figure 3: Monthly sea surface temperatures relative to 1971-2000 baseline. Source: Climate Reanalyzer, Climate Change Institute at the University of Maine, based on data from NOAA Optimum Interpolation Sea Surface Temperature (OISST).

since the post-industrial revolution low point in 1909 (US EPA, 2016). The years 2023 and 2024 have shattered all previous records (see Figure 3).

OAW started producing serious economic impacts in Oregon in 2007, when oyster hatchery production collapsed. As ocean water becomes more acidic, it becomes so corrosive that it eats away young oyster shells before they can form. Since that time, some producers have shifted operations to other states, while others have adapted by switching to closed tank operations (Oregon Department of Fish and Wildlife, 2022).

Another OAW effect – hypoxia – threatens a much broader range of species in the ocean ecosystem food web that will make adaptation far more challenging. Hypoxia, a deficit of dissolved oxygen, is occurring more frequently along the Oregon Coast due to warmer waters and disruption of wind and upwelling patterns (OAH 2022). Hypoxia threatens the entire shellfish industry in the region, including Dungeness crabs and could lead to the migration or mass die offs of groundfish such as sole and lingcod. While the hypoxia season is a normal occurrence, the recent severity, duration, and extent of hypoxic conditions is unprecedented (Barth et al., 2024). New research has found that the fraction of near-bottom water that is hypoxic on average during the summer upwelling season increased over time from nearly absent (2%) in 1950–1980, to 24% in 2009–2018, to 56% in 2021 (Barth et al., 2024). Widespread and increasing near-bottom hypoxia is consistent with increased upwelling-favorable wind forcing under climate change.

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Yet another consequence of OAW along the Oregon Coast is an increase in the severity and frequency of harmful algae blooms (HAB) known as red, brown, or purple tides. These algae blooms produce marine biotoxins that are harmful to humans when ingested through consumption of shellfish. In May of 2024, the entire Oregon coast was closed to mussel harvesting because of these biotoxins. Clam and oyster harvesting were also shut down along several stretches (Ehrlich, 2024).

These closures are likely to become more frequent and expansive as climate change unfolds since warming waters increase the likelihood of harmful algal blooms. For example, a 2009-2010 ocean warming event was associated with the highest levels of domoic acid and saxitoxins found over the course of a 2007 to 2012 project (McKibben et al., 2015). According to NOAA, HAB events in Oregon along the West Coast are increasing in frequency, duration, and intensity and are increasingly threatening to coastal economies, ecosystems, and public health (Suddleson, 2020).

Dungeness Crab Harvest at Serious Risk

Oregon Dungeness crab is an international delicacy, and the annual worth of Oregon's harvest is over $60 million. In its 2022 biennial report, the Oregon Coordinating Council on Ocean Acidification and Hypoxia noted several stressors to Oregon's crab fishery from OAW and hypoxia. These include (among others) lower reproductive success, adverse effects on larval growth and shell formation, and higher rates of entanglements in fishing gear due to shifting ranges of commercial species.

In 2023, research revealed another risk previously unknown to climate scientists – ocean acidification may be causing crabs to lose their sense of smell (Durant et al., 2023). Because Dungeness crabs have poor eyesight, they rely strongly on their sense of smell to detect food and predators.

The new study finds ocean acidification interferes with the olfactory nerve and the authors conclude that near-future CO_2 levels will impact the threshold of detection of food by crabs and lead to a decline in individual fitness and, consequently, population-levels of Dungeness crab.

Ecosystems

Climate change will have profound effects on Oregon's native fish, wildlife, trees and plants and the ecosystems in which they are embedded. In response to sea level rise, increases in temperature and changes in precipitation patterns, certain ecosystems like glaciers and salt marshes may disappear entirely. Others may be severely degraded in portions of their ranges.

For example, Douglas fir forests are already disappearing from lower elevations in the warmest and driest (< 35 inches annually) regions of southern Oregon where mortality associated with the flatheaded fir borer is rising dramatically. Big leaf maple (Betzen et al., 2021) and western red cedar (Andrus et al., 2024) are other tree species suffering regional declines due to climate change. Coldwater fisheries are being stressed in mainstream rivers, forcing native salmon, trout, and steelhead to move, migrate, or tolerate the increasingly warm summers but with lower physiological performance and reproductive success (Barrett & Armstrong, 2022). Every native ecosystem in Oregon is being affected.

The concept of ecosystem services provides a framework for tallying the economic costs to Oregon's households, businesses, and government agencies associated with these climate–driven losses and damage to species and ecosystems. Every natural ecosystem provides a host of services that support economic activity in one way or the other. These services are generally classified into three main categories – (1) regulating services, such as control of flooding and carbon sequestration; (2) cultural services, such as providing sites for recreation and tourism activities, and (3) provisioning services, such as supplying local communities with firewood, plants, and animals for direct consumption (Pascual et al., 2011). Globally, the value of these ecosystem services has been estimated to be nearly to $170 trillion per year (Kubiszewski et al., 2020). As such, the loss and degradation of native species and ecosystems is no small matter from an economic perspective.

To illustrate, consider the three ecosystems touched on above. If the Douglas fir forests now affected by severe or very severe mortality from the flatheaded fir borer (~150,000 acres) were permanently lost, the value of these forests for timber, water, recreation, wildlife, carbon sequestration and other ecosystem services would be substantially reduced. For example, according to US Forest Service data, healthy forests in this area are capturing roughly 2.8 metric tons CO_2 per acre per year over and above what is released by tree mortality (Forest Inventory and Analysis Program, 2024). The cost of eliminating this sequestration service can be estimated using the "social cost of carbon" which is an estimate of the cost of the additional damages created by each extra ton of carbon dioxide emitted.

There is considerable scientific debate about the social cost of carbon and estimates vary. For the purposes of discussion here, we adopt a value used by the EPA for guidance throughout government agencies: $240 per ton in 2023 dollars (National Center for Environmental Economics, Office of Policy & Climate Change Division, Office of Air and Radiation, 2023, Table A.5.1). This value translates into a cost estimate of roughly $100 million per year if the sequestration services provided by the 150,000 acres now severely affected by the flatheaded fir borer were permanently eliminated. Some researchers believe that the true social cost of carbon could be double or more than the EPA guidance, and published estimates of the social cost of carbon have increased substantially over the past decade (Tol, 2023). If so, the estimate of $100 million per year would be higher as well.

Climate change will have profound effects on Oregon's native fish, wildlife, trees and plants and the ecosystems in which they are embedded.

With respect to salt marshes, Oregonians risk losing over $450 million in ecosystem services each year depending on the degree of sea level rise. But one important adaptation strategy is the restoration or creation of new salt marshes in areas that will be newly inundated as sea level rise progresses through activities such as removal of dikes and barriers and planting salt marsh vegetation (Wang et al., 2022). This adaptation approach trades off one ecosystem service (agricultural production) for others (e.g., shellfish production, etc.) and so any restoration program should pass a benefit-cost test that considers the value of agricultural output forgone now to restore a broad range of salt marsh ecosystem services in the future.

Oregon Salt Marshes may Vanish by 2100

Less than 1% of the earth is covered by salt marshes, yet they are estimated to account for ~20% of the global value of ecosystem services (Costanza et al., 2014). They are exceptionally productive from the standpoint of human wellbeing, providing essential services such as flood control, shoreline protection and purification of water as well providing habitat for shorebirds, fish and shellfish.

In Oregon, coastal wetlands, including salt marshes, once encompassed 113,000 acres. Their extent has been reduced to 41,000 acres due to diking and land use conversion (Lyle et al., 2023). FEMA maintains a current estimate of ecosystem service values for a wide range of ecosystem types, and the current average for salt marshes and other coastal ecosystems is $11,048 per acre in 2023 dollars (FEMA, 2022). As such, salt marshes and other coastal ecosystems now provide Oregonians over $450million in ecosystem service benefits each year. As just one example of these, Runyan (2009) estimated that Oregonians spend over $250 million a year on travel costs, local recreation expenses, and equipment related to shellfishing.

Under high sea level rise scenarios, all salt marsh is predicted to be lost in Oregon by 2100 (Thorne et al., 2018). One possible response would be to restore salt marshes from lands now used for grazing cattle and crops at a cost that could range between $184,000 and $281,000 per acre (Wang et al., 2022).

Lastly, with respect to the loss of glacial ecosystems, one specific ecosystem service is related to recreational use. Mountain climbing outfits use these glaciers as pathways to the higher peaks but cease operations once loose rocks and meltwater make it too dangerous in the late summer. According to one mountaineering club in Central Oregon, climate change has already shortened the climbing season by over a month (Kohn, 2020).

Another important ecosystem service provided by glacial ecosystems is the cold water they provide to downstream freshwater fisheries, keeping them productive through the hot dry summer months. It is difficult to isolate and monetize this contribution, but one signal of value is the cost of replacing this service by installing “water conditioning” systems at downstream dams to regulate stream temperatures and streamflow to allow fish to thrive, despite the increasingly extreme conditions associated with climate change and the loss of cold-water inputs from glaciers (Ciocci, 2021). This adaptation response also comes with a clear economic tradeoff – flood control, boating, and recreation at reservoirs vs. protecting coldwater fish by drawing down reservoirs earlier in the year.

Global Disruptions

Oregon's economy is inextricably linked to the broad macroeconomy of the United States and the rest of the world. As climate change impacts the entire planet, changes in other locations will reverberate through the global economy and impact the economy here in Oregon. Macroeconomists have worked to understand these interconnections and produce estimates of global-level impacts to the economy. This is a challenging task as the concentration of greenhouse gases in the atmosphere is beyond levels previously experienced by industrialized civilization (Meinshausen et al., 2011). Researchers must therefore make difficult decisions about how to incorporate data from the past into projections of the future. Estimates of the global consequences of climate change vary substantially across studies as different groups of researchers incorporate different factors into their analysis and use alternative methodologies. In other words, the research on the future macroeconomic impacts of climate change is unsettled and there is substantial disagreement between researchers on specific numbers.

A key factor driving these varying results is the extent to which researchers take adaptation into account. In other words, some models assume that government policies will continue much as they are today. Others assume that societies around the world will work to lower carbon emissions and reduce the impact of climate change through policy changes and corresponding changes in behavior. As one might expect, studies that incorporate a degree of adaptation tend to estimate a lower impact of climate change, as some of the effects will be mitigated by those adaptations.

As climate change impacts the entire planet, changes in other locations will reverberate through the global economy and impact the economy here in Oregon.

When scientists report different results under different sets of assumptions, data, and models, "meta-analysis" is a common practice. Meta-analyses combine estimates from multiple studies to try to improve accuracy. Most studies in this area focus on Gross Domestic Product (GDP), the market value of all the goods and services produced each year. A recent meta-analysis concluded that the global losses due to climate change may result in a reduction of GDP by ten percent over the next several decades, depending on how much warming occurs (Tol, 2024). While this may be a reasonable average of current projections, a single number does not fully capture the risk profile of climate change, which includes risks of much greater losses (Rising et al., 2022). Some peer-reviewed published estimates of future losses are more than two times higher than this average (Newell et al., 2021).

What does that mean for Oregon? First, we note that estimates of aggregate global impacts do not translate directly to each individual location that forms part of the aggregate; in other words, if the global losses are indeed ten percent of GDP, the losses to Oregon could be higher or lower than ten percent. That said, we will illustrate what this number could mean for Oregon, as arguments could be made that the effects of climate change on Oregon could be higher or lower than the average across the rest of the world.

Oregon's current annual GDP is about $320 billion (U.S. Bureau of Economic Analysis, 2024). If the projected decrease in GDP over the next few decades manifested today, the loss of 10% of GDP would equal $32 billion, or roughly $7,500 per Oregonian per year. If global losses are higher, losses in Oregon may be higher as well, although the previous caveat about applying global estimates directly to Oregon still applies.

Of course, changes in GDP do not translate one-to-one to household incomes; changes in GDP manifest both as changes in incomes and in prices of goods and services. Other recent global analyses consider effects on income, rather than GDP. For example, a study published in Nature estimated that the world economy is already committed to an income reduction of 19% within the next 26 years as a consequence of greenhouse gases that are already in the atmosphere (Kotz, Levermann, et al., 2024). If this cost manifested today, it would mean an income reduction of $12,000 per year for the average Oregonian.

One sector which merits particular attention is the cost of food, as Oregonians (like others around the United States and beyond) have suffered significant inflation in the cost of food over the past several years. Since our food supply chain is interconnected globally, the price of food in Oregon will be influenced by changes in

the climate around the world, even if some of the worst predictions of changes in Oregon do not come to pass. One study using past temperature variations to estimate the effects of future temperature increases concluded that, by 2035, climate change may increase the price of food in North America by roughly 2% each year (Kotz, Kuik, et al., 2024, Figure 2).

Others are examining these longer-term and global trends through different lenses. For example, Consumer Reports commissioned a study aiming to calculate the costs of climate change through the lens of children born in particular U.S. cities in 2024 (ICF Incorporated, L.L.C., 2024). We do not focus on the numbers presented in their report as their methodology and metrics differ substantially from other studies, though their broad conclusion, that climate change poses substantial economic risks, is in line with other work. We aim to conduct similar analyses for Oregonians in the future.

Finally, there is still considerable uncertainty around the impact of greenhouse gases in the future, with distinguished scientists warning the changes and impacts will become far more severe without prompt corrective action (Ripple et al., 2024). There also is considerable uncertainty regarding the future choices made by governments to prevent climate change and adapt to its effects. For example, the estimates presented above take some degree of adaptation into account. However, if societies choose not to engage in the adaptations assumed by the studies that comprise the meta-analysis, those assumptions will be invalid and therefore the studies' estimates will be invalid too. We therefore recommend that governments, businesses, and individuals consider the costs and benefits of mitigation and adaptation behaviors by considering scenarios in which no adaptation occurs.

What's Next?

For many Oregonians, our changing climate represents an area of great concern. Existing research on the economic effects of climate change validate and underscore these fears: the results we have summarized in this report suggest that the average household in Oregon can reasonably expect to suffer damages in the tens of thousands of dollars per year under current emissions scenarios. Some of these costs will emerge in the coming years and decades, while others, such as impacts of wildfire and air quality, are already here.

The results we have summarized in this report suggest that the average household in Oregon can reasonably expect to suffer damages in the tens of thousands of dollars per year under current emissions scenarios.

The good news is that these scenarios aren't fixed: action we take today to both reduce climate-damaging emissions and adapt to the effects of climate change will have a measurable impact on these costs. Our goal in compiling this report is to highlight that existing work provides a sound and reasonable basis for public and private investments in climate interventions. While some interventions may come with a substantial price tag, the cost of inaction may be even greater. At the very least, we must take advantage of the available knowledge to weigh costs and benefits.

In this report, we have also highlighted several areas where the qualitative effects of climate change are reasonably-well understood, but where researchers have not yet been able to conduct the sorts of analyses to put numbers on the costs. This does not mean that there are no costs associated with these changes, nor that these risks are not worth examining – simply that the current research is incomplete. Among other interventions, we hope that policymakers, non-profits, private foundations, and anyone who is concerned about our future consider additional investments in research to understand the local effects of climate change in Oregon and the costs associated with those effects. Climate change threatens everyone's bottom line, and everyone deserves the power to make informed decisions about climate policy and climate action.

Finally, we emphasize once more that there is a great deal of uncertainty in any estimate of the future costs of climate change. While we have worked to provide a reasonable snapshot of existing analyses, the true costs experienced by Oregonians may be higher or lower than the numbers discussed in this report. That said, we are aware that some may use the uncertainty surrounding the effects of climate change to support status quo policies. We disagree with that interpretation. While we may not know every detail of the costs Oregonians can expect to experience as our climate changes, again, we are confident that the costs are substantially greater than zero.

References

Almazroui, M., Islam, M. N., Saeed, F., Saeed, S., Ismail, M., Ehsan, M. A., Diallo, I., O'Brien, E., Ashfaq, M., Martínez-Castro, D., Cavazos, T., Cerezo-Mota, R., Tippett, M. K., Gutowski, W. J., Alfaro, E. J., Hidalgo, H. G., Vichot-Llano, A., Campbell, J. D., Kamil, S., … Barlow, M. (2021). Projected Changes in Temperature and Precipitation Over the United States, Central America, and the Caribbean in CMIP6 GCMs. Earth Systems and Environment, 5(1), 1–24. https://doi.org/10.1007/s41748-021-00199-5

Andrus, R. A., Peach, L. R., Cinquini, A. R., Mills, B., Yusi, J. T., Buhl, C., Fischer, M., Goodrich, B. A., Hulbert, J. M., Holz, A., Meddens, A. J. H., Moffett, K. B., Ramirez, A., & Adams, H. D. (2024). Canary in the forest?—Tree mortality and canopy dieback of western redcedar linked to drier and warmer summers. Journal of Biogeography, 51(1), 103–119. https://doi.org/10.1111/jbi.14732

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M. F. M., & Tangang, F. (2022). The Impact of Heatwaves on Mortality and Morbidity and the Associated Vulnerability Factors: A Systematic Review. International Journal of Environmental Research and Public Health, 19(23), 16356. https://doi.org/10.3390/ijerph192316356

Barrett, H. S., & Armstrong, J. B. (2022). Move, migrate, or tolerate: Quantifying three tactics for cold-water fish coping with warm summers in a large river. Ecosphere, 13(6), e4095. https://doi.org/10.1002/ecs2.4095

Barth, J. A., Pierce, S. D., Carter, B. R., Chan, F., Erofeev, A. Y., Fisher, J. L., Feely, R. A., Jacobson, K. C., Keller, A. A., Morgan, C. A., Pohl, J. E., Rasmuson, L. K., & Simon, V. (2024). Widespread and increasing near-bottom hypoxia in the coastal ocean off the United States Pacific Northwest. Scientific Reports, 14(1), 3798. https://doi.org/10.1038/s41598-024-54476-0

Betzen, J. J., Ramsey, A., Omdal, D., Ettl, G. J., & Tobin, P. C. (2021). Bigleaf maple, Acer macrophyllum Pursh, decline in western Washington, USA. Forest Ecology and Management, 501, 119681. https://doi.org/10.1016/j.foreco.2021.119681

Bureau of Land Management and USDA Forest Service. (2019). 2018 Pacific Northwest Wildland Fire Season: Summary of key events and issues. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd611322.pdf

Chang, H., Loikith, P., & Messer, L. (2021). The June 2021 Extreme Heat Event in Portland, OR, USA: Its Impacts on Ecosystems and Human Health and Potential Adaptation Strategies. Journal of Extreme Events, 08(03), 2175001. https://doi.org/10.1142/S2345737621750014

Ciocci, L. (2021, October 4). Water Temperature Conditioning Enhances Fishery Resources in Washington State. National Hydropower Association. https://www.hydro.org/powerhouse/article/water-temperature-conditioning-enhances-fishery-resources-in-washington-state/

Climate Impacts Group. (2023). In the hot seat: Saving lives from extreme heat in Washington state. University of Washington. https://cig.uw.edu/wp-content/uploads/sites/2/2023/06/CIG-Report-Heat-202-pages.pdf

Climate Reanalyzer (n.d.). Monthly Sea Surface Temperature. Climate Change Institute, University of Maine. Retrieved October 18, 2024, from https://climatereanalyzer.org/clim/sst_monthly/

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global environmental change, 26, 152-158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Dundas, S. J., Capalbo, S., & Sterns, J. (2023). The Economic Implications of Climate Change for Oregon. Oregon Climate Change Research Institute, Oregon State University.

Durant, A., Khodikian, E., & Porteus, C. S. (2023). Ocean acidification alters foraging behaviour in Dungeness crab through impairment of the olfactory pathway. Global Change Biology, 29(14), 4126–4139. https://doi.org/10.1111/gcb.16738

Dye, A. W., Reilly, M. J., McEvoy, A., Lemons, R., Riley, K. L., Kim, J. B., & Kerns, B. K. (2024). Simulated Future Shifts in Wildfire Regimes in Moist Forests of Pacific Northwest, USA. Journal of Geophysical Research: Biogeosciences, 129(2), e2023JG007722. https://doi.org/10.1029/2023JG007722

Ehrlich, A. (2024, June 7). Oregon Coast shellfish harvesting closure expands to clams after poisonings. Oregon Public Broadcasting. https://www.opb.org/article/2024/06/07/oregon-coast-shellfish-mussels-clams-closure/

FEMA. (2022). FEMA Ecosystem Service Value Updates.

Feng, S., Gao, D., Liao, F., Zhou, F., & Wang, X. (2016). The health effects of ambient PM2.5 and potential mechanisms. Ecotoxicology and Environmental Safety, 128, 67–74. https://doi.org/10.1016/j.ecoenv.2016.01.030

Fleishman, E. (2023). Sixth Oregon Climate Assessment. Oregon Climate Change Research Institute, Oregon State University. https://doi.org/10.5399/osu/1161

Forest Inventory and Analysis Program. (2024). Forest Inventory EVALIDator web application (Version 2.1.3) [Computer software]. USDA Forest Service. https://apps.fs.usda.gov/fiadb-api/evalidator

Gu, L., Chen, J., Yin, J., Sullivan, S. C., Wang, H.-M., Guo, S., Zhang, L., & Kim, J.-S. (2020). Projected increases in magnitude and socioeconomic exposure of global droughts in 1.5 and 2 °C warmer climates. Hydrology and Earth System Sciences, 24(1), 451–472. https://doi.org/10.5194/hess-24-451-2020

Headwaters Economics. (2018). The Full Community Costs of Wildfire. https://headwaterseconomics.org/wp-content/uploads/full-wildfire-costs-report.pdf

Hoegh-Guldberg, O., Cai, R., Poloczanska, E. S., Brewer, P. G., Sundby, S., Hilmi, K., Fabry, V. J., Jung, S., Skirving, W., & Stone, D. A. (2014). The ocean. https://munin.uit.no/handle/10037/6969

ICF Incorporated, L.L.C. (2024). Cost of Climate Change to an American Born in 2024. Consumer Reports. https://advocacy.consumerreports.org/wp-content/uploads/2024/04/ICF-CR-Cost-of-Climate-Change-Study.pdf

Institute for Policy Research and Engagement. (2024). Oregon Climate Change Social Vulnerability Assessment. Institute for Policy Research and Engagement, University of Oregon. https://www.oregon.gov/lcd/CL/Documents/062624_Climate_Change_Vulnerability_Analysis_DRAFT.pdf?utm_medium=email&utm_source=govdelivery

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (p. 184). https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_FullVolume.pdf

Jones, B. A. (2018). Willingness to pay estimates for wildfire smoke health impacts in the US using the life satisfaction approach. Journal of Environmental Economics and Policy, 7(4), 403–419. https://doi.org/10.1080/21606544.2018.1463872

Jung, I. W., & Chang, H. (2012). Climate change impacts on spatial patterns in drought risk in the Willamette River Basin, Oregon, USA. Theoretical and Applied Climatology, 108(3–4), 355–371. https://doi.org/10.1007/s00704-011-0531-8

Kohn, M. (2020). Shrinking glaciers impact life in Central Oregon. Deschutes River Conservancy. https://www.deschutesriver.org/in-the-media/shrinking-glaciers-could-impact-life-in-central-oregon

Kolstoe, S., & Cameron, T. A. (2017). The non-market value of birding sites and the marginal value of additional species: Biodiversity in a random utility model of site choice by eBird members. Ecological Economics, 137, 1–12.

Kolstoe, S., Cameron, T. A., & Wilsey, C. (2018). Climate, Land Cover, and Bird Populations: Differential Impacts on the Future Welfare of Birders across the Pacific Northwest. Agricultural and Resource Economics Review, 47(2), 272–310. https://doi.org/10.1017/age.2018.9

Kotz, M., Kuik, F., Lis, E., & Nickel, C. (2024). Global warming and heat extremes to enhance inflationary pressures. Communications Earth & Environment, 5(1), 116. https://doi.org/10.1038/s43247-023-01173-x

Kotz, M., Levermann, A., & Wenz, L. (2024). The economic commitment of climate change. Nature, 628(8008), 551–557. https://doi.org/10.1038/s41586-024-07219-0

Kubiszewski, I., Costanza, R., Anderson, S., & Sutton, P. (2020). Chapter 5: The future value of ecosystem services: global scenarios and national implications. https://www.elgaronline.com/edcollchap/edcoll/9781788976862/9781788976862.00016.xml

Lyle, J. T., Graves, R. A., Carter, J., & Tabor, L. (2022). Oregon's Blue Carbon Ecosystems: State Of The Science, A Summary Of The Current Understanding Of The Climate Mitigation Potential Of Oregon'S Coastal And Marine Habitats. https://doi.org/10.25923/jw5w-t894

McKibben, S. M., Watkins-Brandt, K. S., Wood, A. M., Hunter, M., Forster, Z., Hopkins, A., Du, X., Eberhart, B.-T., Peterson, W. T., & White, A. E. (2015). Monitoring Oregon Coastal Harmful Algae: Observations and implications of a harmful algal bloom-monitoring project. Harmful Algae, 50, 32–44. https://doi.org/10.1016/j.hal.2015.10.004

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J.-F., Matsumoto, K., Montzka, S. A., Raper, S. C. B., Riahi, K., Thomson, A., Velders, G. J. M., & van Vuuren, D. P. P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. Climatic Change, 109(1), 213. https://doi.org/10.1007/s10584-011-0156-z

National Center for Environmental Economics, Office of Policy & Climate Change Division, Office of Air and Radiation. (2023). EPA Report on the Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances. U.S. Environmental Protection Agency.

Netusil, N. R., Kincaid, M., & Chang, H. (2014). Valuing water quality in urban watersheds: A comparative analysis of Johnson Creek, Oregon, and Burnt Bridge Creek, Washington. Water Resources Research, 50(5), 4254–4268. https://doi.org/10.1002/2013WR014546

Newell, R. G., Prest, B. C., & Sexton, S. E. (2021). The GDP-Temperature relationship: Implications for climate change damages. Journal of Environmental Economics and Management, 108, 102445. https://doi.org/10.1016/j.jeem.2021.102445

NOAA Fisheries. (2023, July 25). Understanding Ocean Acidification | NOAA Fisheries (National). NOAA. https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification

ODOT. (2012). ODOT's Climate Change Adaptation Strategy Report.

Oregon Department of Fish and Wildlife. (2022). Ocean Acidification and Hypoxia. Ocean Acidifcation and Hypoxia. https://www.dfw.state.or.us/MRP/ocean_ah/

Oregon Department of Forestry, 2020. ODF Fire Report for Monday, September 21, 2020. https://odffire.com/2020/09/21/odf-fire-report-for-monday-sept-21-2020/

Oregon Department of Forestry. (2023, June 30). Oregon's Landscape Resiliency Strategy, Progress Report: June 30, 2023. https://www.oregon.gov/odf/fire/documents/olrs-progress-report.pdf

Oregon Health Authority. (2023). Climate and Health in Oregon: 2021-2022 Report. https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/CLIMATECHANGE/Documents/le-105251_23.pdf

Oregon State Board of Agriculture. (2021). 2021 Report. https://www.oregon.gov/ODA/shared/Documents/Publications/Administration/BoardReport.pdf

Oregon Water Resources Department. (2015). 2015 Statewide Long-Term Water Demand Forecast (Oregon's Integrated Water Resources Strategy). https://www.oregon.gov/OWRD/wrdpublications1/OWRD_2015_Statewide_LongTerm_Water_Demand_Forecast.pdf

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., Armsworth, P., Christie, M., Cornelissen, H., & Eppink, F. (2011). The Economics of Valuing Ecosystem Services and Biodiversity. In The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Routledge.

Qiu, M., Li, J., Gould, C. F., Jing, R., Kelp, M., Childs, M., Kiang, M., Heft-Neal, S., Diffenbaugh, N., & Burke, M. (2024). Mortality Burden From Wildfire Smoke Under Climate Change (Working Paper 32307). National Bureau of Economic Research. https://doi.org/10.3386/w32307

Ripple, W. J., Wolf, C., Gregg, J. W., Rockström, J., Mann, M. E., Oreskes, N., … & Crowther, T. W. (2024). The 2024 state of the climate report: Perilous times on planet Earth. BioScience, biae087, https://doi.org/10.1093/biosci/biae087

Rising, J., Tedesco, M., Piontek, F., & Stainforth, D. A. (2022). The missing risks of climate change. Nature, 610(7933), 643–651. https://doi.org/10.1038/s41586-022-05243-6

Runyan, D. (2009). Fishing, Hunting, Wildlife Viewing, and Shellfishing in Oregon 2008 State and County Expenditure Estimates. Retrieved from Dean Runyan: https://www.dfw.state.or.us/agency/docs ….

Rupp, D. E., Abatzoglou, J. T., & Mote, P. W. (2017). Projections of 21st century climate of the Columbia River Basin. Climate Dynamics, 49(5), 1783–1799. https://doi.org/10.1007/s00382-016-3418-7

Schiffman, R. (2024). In Warming World, Global Heat Deaths Are Grossly Undercounted. Yale E360. https://e360.yale.edu/features/kristie-ebi-interview

Song, X., Wang, S., Hu, Y., Yue, M., Zhang, T., Liu, Y., Tian, J., & Shang, K. (2017). Impact of ambient temperature on morbidity and mortality: An overview of reviews. Science of The Total Environment, 586, 241–254. https://doi.org/10.1016/j.scitotenv.2017.01.212

Sproles, E. A., Nolin, A. W., Rittger, K., & Painter, T. H. (2013). Climate change impacts on maritime mountain snowpack in the Oregon Cascades. Hydrology and Earth System Sciences, 17(7), 2581–2597. https://doi.org/10.5194/hess-17-2581-2013

Suddleson, M. (2020, September 24). Risk of Toxic Shellfish on West Coast Increases with Water Temperature. NCCOS Coastal Science Website. https://coastalscience.noaa.gov/news/risk-toxic-shellfish-west-coast-increases-water-temperature/

Thorne, K., MacDonald, G., Guntenspergen, G., Ambrose, R., Buffington, K., Dugger, B., Freeman, C., Janousek, C., Brown, L., Rosencranz, J., Holmquist, J., Smol, J., Hargan, K., & Takekawa, J. (2018). U.S. Pacific coastal wetland resilience and vulnerability to sea-level rise. Science Advances, 4(2), eaao3270. https://doi.org/10.1126/sciadv.aao3270

Tol, R. S. J. (2023). Social cost of carbon estimates have increased over time. Nature Climate Change, 13(6), 532–536. https://doi.org/10.1038/s41558-023-01680-x

Tol, R. S. J. (2024). A meta-analysis of the total economic impact of climate change. Energy Policy, 185, 113922. https://doi.org/10.1016/j.enpol.2023.113922

U.S. Bureau of Economic Analysis. (2024, September 27). GDP by State. https://www.bea.gov/data/gdp/gdp-state

U.S. Consumer Product Safety Commission. (2024). Notice of Availability of Final Guidance for Estimating Value per Statistical Life. Federal Register, 89, 277740–27751.

USDA Forest Service. 2024. Oregon: Wildfire Likelihood. Wildfire Risk to Communities. https://wildfirerisk.org/explore/wildfire-likelihood/41/

U.S. Environmental Protection Agency. (2011). The Benefits and Costs of the Clean Air Act from 1990 to 2020 (Final Report-Rev. A).

US EPA. (2016, June 27). Climate Change Indicators: Sea Surface Temperature [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

US EPA. (2021, December 6). How's My Waterway? [Overviews and Factsheets]. US EPA. https://mywaterway.epa.gov

Wang, J.-J., Li, X.-Z., Lin, S.-W., & Ma, Y.-X. (2022). Economic Evaluation and Systematic Review of Salt Marsh Restoration Projects at a Global Scale. Frontiers in Ecology and Evolution, 10. https://doi.org/10.3389/fevo.2022.865516

White, R. H., Anderson, S., Booth, J. F., Braich, G., Draeger, C., Fei, C., Harley, C. D. G., Henderson, S. B., Jakob, M., Lau, C.-A., Mareshet Admasu, L., Narinesingh, V., Rodell, C., Roocroft, E., Weinberger, K. R., & West, G. (2023). The unprecedented Pacific Northwest heatwave of June 2021. Nature Communications, 14(1), 727. https://doi.org/10.1038/s41467-023-36289-3

Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., & Tong, S. (2012). Ambient Temperature and Morbidity: A Review of Epidemiological Evidence. Environmental Health Perspectives, 120(1), 19–28. https://doi.org/10.1289/ehp.1003198

Zald, H. S. J., & Dunn, C. J. (2018). Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecological Applications, 28(4), 1068–1080. https://doi.org/10.1002/eap.1710

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