Case No. 18-36082

**IN THE UNITED STATES COURT OF APPEALS
FOR THE NINTH CIRCUIT**

KELSEY CASCADIA ROSE JULIANA, *et al.*,
Plaintiffs-Appellees,
v.
UNITED STATES OF AMERICA, *et al.*,
Defendants-Appellants.

On Interlocutory Appeal Pursuant to 28 U.S.C. § 1292(b)

DECLARATION OF STEVEN W. RUNNING IN SUPPORT OF PLAINTIFFS' URGENT MOTION UNDER CIRCUIT RULE 27-3(b) FOR PRELIMINARY INJUNCTION

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I, Steven W. Running, hereby declare and if called upon would testify as follows:

1. In this Declaration, I offer my expert opinion about how excessive greenhouse gas (GHG) emissions, largely from the burning of fossil fuels, are causing climate change that is dangerously warming the surface of the Earth and causing devastating impacts to the Youth Plaintiffs in this case. Because there is a decades-long delay between the release of carbon dioxide (CO_2) and the resultant warming of the climate, these Youth Plaintiffs have not yet experienced the full amount of warming that will occur from emissions already released. The only way to avoid the most devastating impacts is to begin reducing GHG emissions immediately.

2. In 1979, I received my Ph.D. in Forest Ecology from Colorado State University. Since 1979, I have been with the University of Montana, where I retired in 2017. I now am a University Regents Professor Emeritus of Global Ecology in the College of Forestry and Conservation. In 1983, I founded the Numerical Terradynamic Simulation Group (NTSG), my global research team of graduate students and staff, at the University of Montana. I have published over 300 scientific articles and two books, and have been honored with several awards. I have served on the Standing Committee for Earth Studies of the National Research Council and on the federal Interagency Carbon Cycle Science Committee. I have also served as a Co-Chair of the National Center for Atmospheric Research Community Climate System Model Land Working Group, a Member of the International Geosphere-

Biosphere Program Executive Committee, and a Member of the World Climate Research Program, Global Terrestrial Observing System. I recently completed serving on the advisory National Aeronautics and Space Administration ("NASA") Earth Science Subcommittee, and the National Oceanic and Atmospheric Administration ("NOAA") Science Advisory Board Climate Working Group. I currently co-Chair the National Academy of Sciences Standing Committee on Earth Science and Applications from Space. In 2007, I shared the Nobel Peace Prize with the Intergovernmental Panel on Climate Change ("IPCC") and Al Gore as a chapter Lead Author for the 4th Assessment of the IPCC. I am an elected Fellow of the American Geophysical Union and am designated a Highly Cited Researcher by the Institute for Scientific Information.

3. I serve in a pro bono capacity as an expert witness for Plaintiffs in this action. A true and correct copy of my Expert Report in this litigation was filed in support of Plaintiffs' Opposition to Defendants' Motion for Summary Judgment in the District Court at ECF No. 275. A supplemental version of my Expert Report was served on Defendants on September 12, 2018 and is attached hereto as **Exhibit 1**. My professional and educational experience is summarized in my curriculum vitae, a true and correct copy of which is attached as Exhibit A to **Exhibit 1** of this Declaration.

Anthropogenic CO_2 Emissions and Other Greenhouse Gases Are Warming Earth's Surface and Causing Climate Change

4. In 1896, Svante Arrhenius, a Swedish chemist, used his understanding of the basic physics of how molecules like CO_2 differentially transmit shortwave solar radiation, but absorb longwave thermal radiation, to postulate that the then-new practice of burning fossil fuels that emit CO_2 could one day warm the global atmosphere. In the first half of the 19th Century, Arrhenius' scientific theory was confirmed by other scientists, such as Guy S. Callendar. Due to the concern about global warming from burning fossil fuels, in 1958, Dr. David Keeling (through NOAA) began the modern monitoring of atmospheric CO_2 at Mauna Loa, Hawaii, a remote location not near any local CO_2 sources. As Arrhenius postulated, and Callendar confirmed, Keeling's monitoring data proved that CO_2 has continued to rise every year from 1958 to the present from an initial concentration of 316 ppm in 1958, to an annual average level of 409 in 2018 (see **Figure 1**).

5. There is a scientific consensus that the rise in atmospheric CO_2 that we are witnessing is attributable to human activities, primarily the burning of fossil fuels.

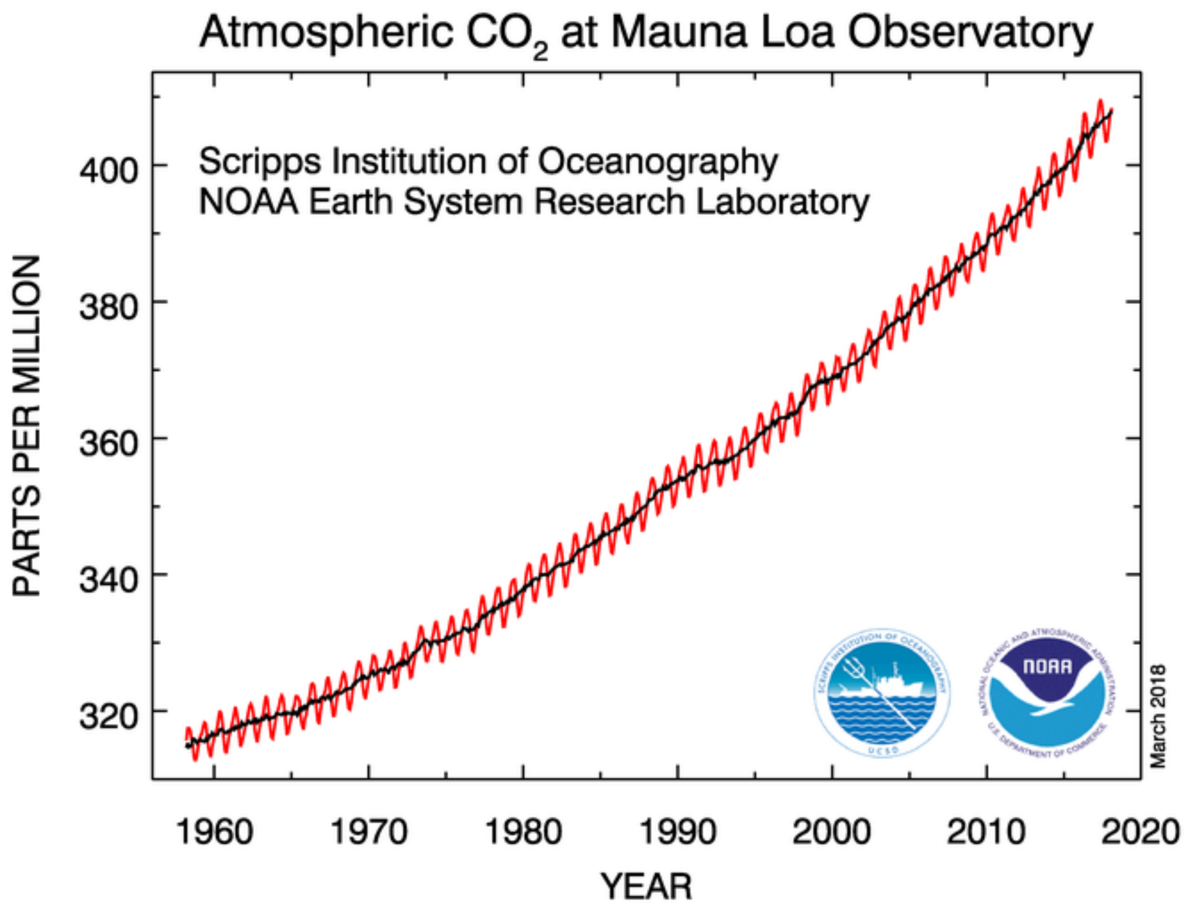
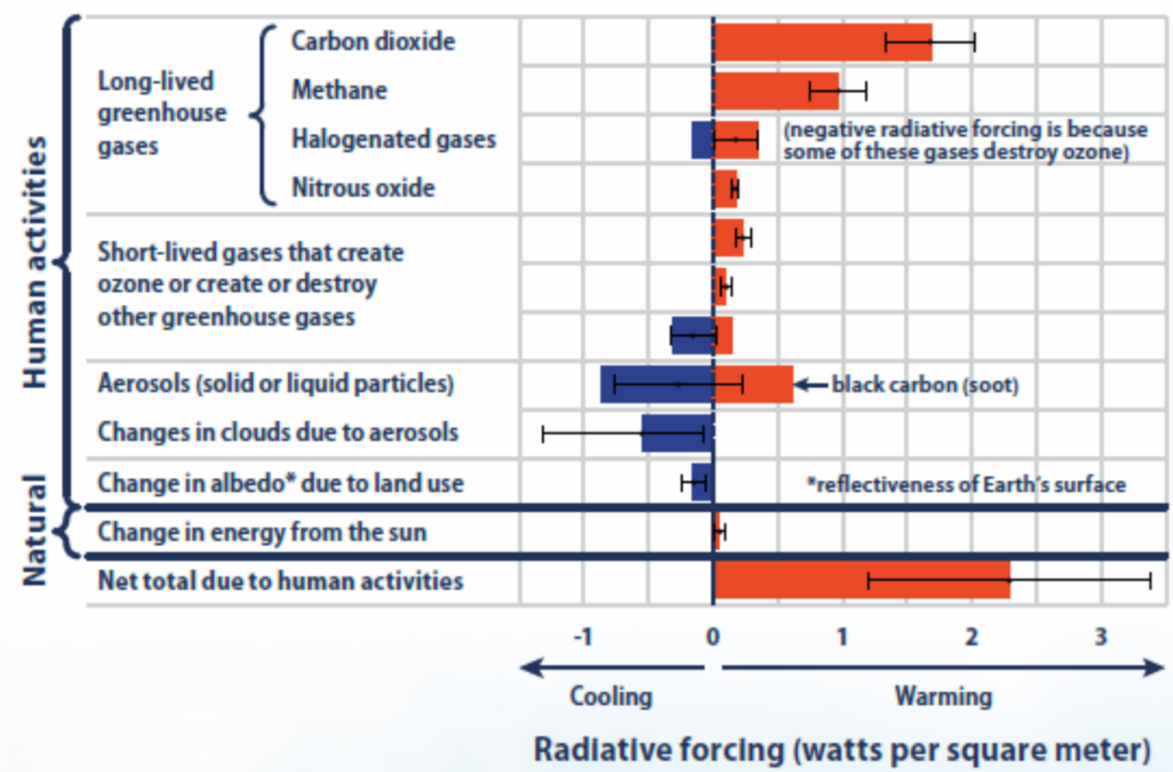


Figure 1. *Atmospheric CO_2 concentration measured at Mauna Loa observatory from 1958 to the present.* (https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html)

6. The Mauna Loa measurements have been replicated at dozens of stations worldwide, all of which confirm CO_2 concentrations are growing, year after year.

7. It is incontrovertible that, if GHG emissions remain as they are today, atmospheric carbon dioxide concentrations will continue to climb, with ever worsening impacts to these young Plaintiffs.

Figure 2. Radiative Forcing Caused by Human Activities Since 1750



8. The IPCC 5th Assessment[1] summarized what scientists have long known, that increasing CO_2 has changed the Earth's energy balance as shown here in **Figure 2**. The energy imbalance of Earth has increased to 2.3 W/M^2. This new energy is roughly equivalent to 2500 Camp Creek fires ***per day*** burning around the world. It is this increase in trapped energy that has now directly resulted in increasing air temperatures at the national and global scales.

[1] IPCC, 2013, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

9. The continuous rise in atmospheric CO_2 has in fact caused global and national air temperatures to rise, as measured by U.S. weather stations. The 2017 National Climate Assessment found that global air temperatures had risen by 1.8° F (1.06°C) between 1901 and 2016.[2] It is irrefutable and has been well known for over ten decades that, as CO_2 concentrations increase, the surface of the planet warms and the oceans warm. That global warming causes climate change and has many harmful effects on ecosystems and humans, as discussed below. It is as if the Earth has a constant fever, and just as in the human body, even a slight rise in temperature weakens the organism, increases vulnerability of the organism, and can have dangerous long-term effects on the system.

10. The increased concentrations of GHGs in our atmosphere have raised global surface temperature by about 1.8°F (1.06°C) from 1901 and 2016, which is above, probably well above, the maximum warming of the Holocene era, the period of relatively stable climate over the last 10,000 years over which human civilization developed. In the last 30 years, the acceleration of change has intensified as the Earth has been warming at a rate three times faster than that over the previous one hundred years. According to NASA, 2014 was the hottest year on record, until 2015 broke that record. 2016 exceeded both 2014 and 2015, marking the first time since modern recordkeeping began that three consecutive years were the hottest years on record.

[2] USGCRP, 2017, *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, https://science2017.globalchange.gov/.

2017 was the third warmest year in NOAA's 138-year climate record, behind 2016 (warmest) and 2015 (second warmest).[3] Since 1960, global average air temperature has shown a progressive increase (**Figure 3**).

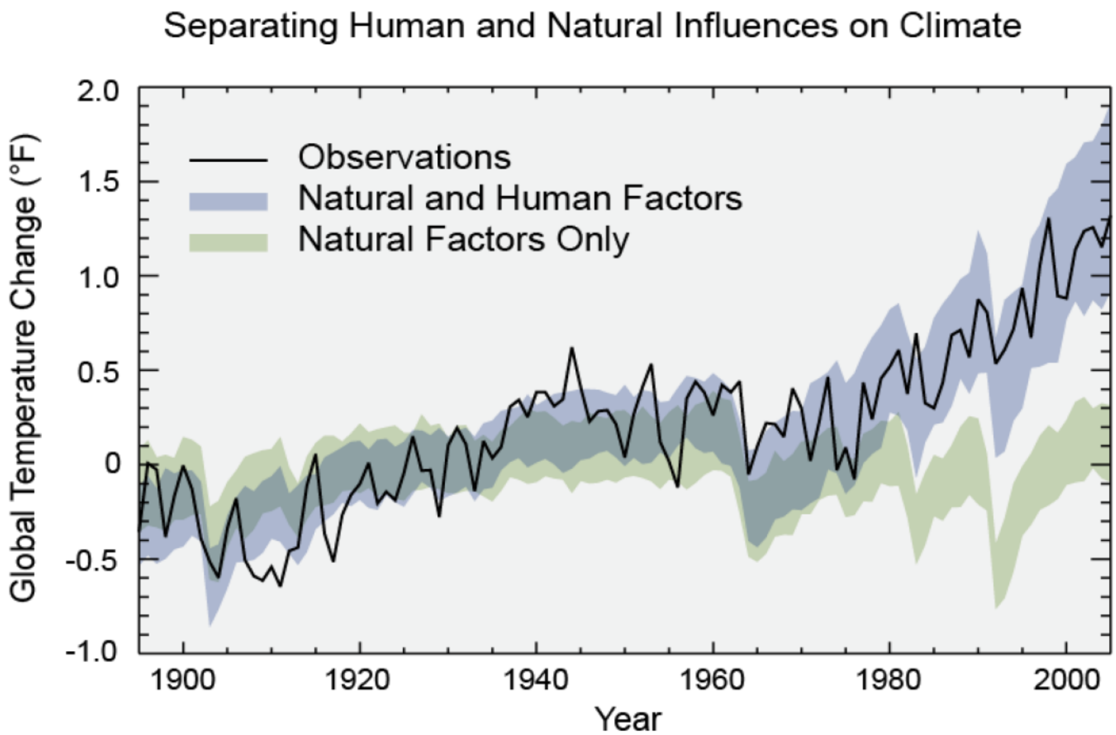


Fig. 1. Human and Natural Influences on Climate. Source: Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Clima Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

Figure 3.

U.S. Greenhouse Gas Emissions Released Into the Atmosphere Contribute to Climate Change Harms and Make Stabilizing the Climate System More Difficult.

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[3] NOAA, *2017 Was 3rd Warmest Year on Record for the Globe*, https://www.noaa.gov/news/noaa-2017-was-3rd-warmest-year-on-record-for-globe (last visited Jan. 18, 2018).

11. Unabated U.S. greenhouse gas emissions released into the atmosphere result in measurable change in atmospheric carbon dioxide concentrations and those changes result in harms.

12. To put this in context, every 7.8 gigatons of CO_2 released into the atmosphere increases the global average CO_2 concentration by 1 part per million and every 1,000 gigatons of CO_2 released increases the average global temperature by 1.0º C to 2.1º C.[4]

13. The United States released 4.9 gigatons of CO_2 in 2016,[5] pushing the atmospheric concentration up more than 0.6 ppm in just one year.[6] Because there is a decades-long delay between the release of CO_2 and the resultant warming of the climate, our Nation has not yet experienced the full amount of warming that will occur from the GHG emissions Defendants have already authorized to be released. Importantly, the CO_2 that is released today remains in the atmosphere for thousands of years, making it critical that GHG emissions are reduced immediately, particularly in light of the young ages of the Plaintiffs in this case.

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[4] Matthews H.D., et al., 2009, *The proportionality of global warming to cumulative carbon emissions*. *Nature*.

[5] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016. U.S. EPA. 2018. Pg. ES-6

[6] 1ppm by volume of atmosphere CO_2 is equivalent to 7.81GTCO_2. For source of conversion units, *see* Carbon Dioxide Information Analysis Center - Conversion Tables. https://cdiac.ess-dive.lbl.gov/pns/convert.html#3 (last visited Feb. 5, 2019).

14. Continuing U.S. emissions at the present level for even two years will make it progressively more difficult to stabilize the climate system in this century in order to preserve the critical components for human life on this planet as we know it today, such as ice sheets. The irreversible harms associated with current levels of warming will only increase as GHG emissions continue to rise.

The Climate Change-Induced Aridification Of The West

15. The U.S. 4th National Climate Assessment[7] ("NCA4") is the official report on climate change impacts produced by the United States government. Released in November 2018, the authors of the NCA4 describe in great detail the current and future impacts of climate change in the United States. **Figure 4** summarizes the trend in temperature recorded at the Nation's weather stations over the last century since 1895, compiled for the 4th National Climate Assessment.[8] It is important to note that, in the arid West, these increasing temperatures are causing much of the West to slowly dry out.

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[7] USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, https://nca2018.globalchange.gov/

[8] USGCRP, 2017, *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, https://science2017.globalchange.gov/.

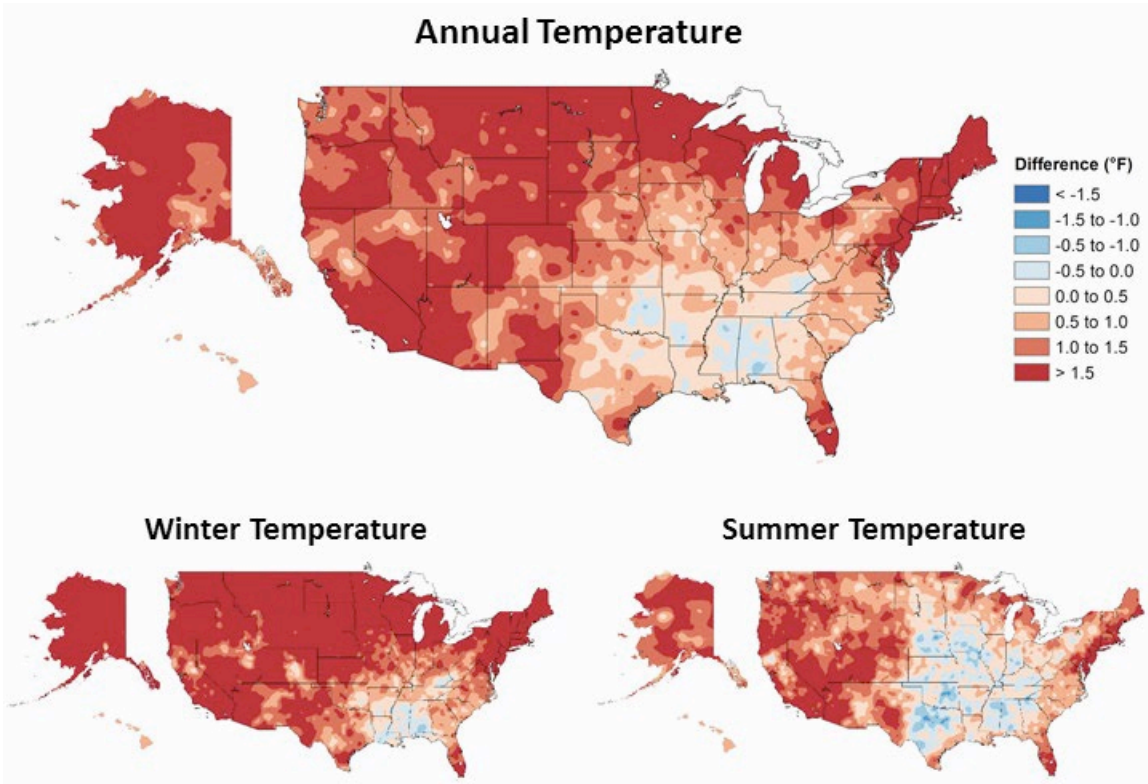

Figure 4. *Trend in weather station air temperatures from 1901 – 2016. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i). Estimates are derived from the nClimDiv dataset.1, 2 (Figure source: NOAA/NCEI). (USGCRP 2017).*

16. **Figure 5** summarizes the change in water stored as snowpack, measured as snow water equivalent ("SWE") in the western United States for the period 1955-2016.[9] According to the authors of the NCA4, "nearly all (92%) of snow courses

[9] Mote, P.W., Li, S., Lettenmaier, D.P., Xiao, M. and Engel, R., 2018, Dramatic declines in snowpack in the western US. *npj Climate and Atmospheric Science*, *1*(1), p.2.

now post negative trends [declining snowpack] over the updated period of record 1955-present."

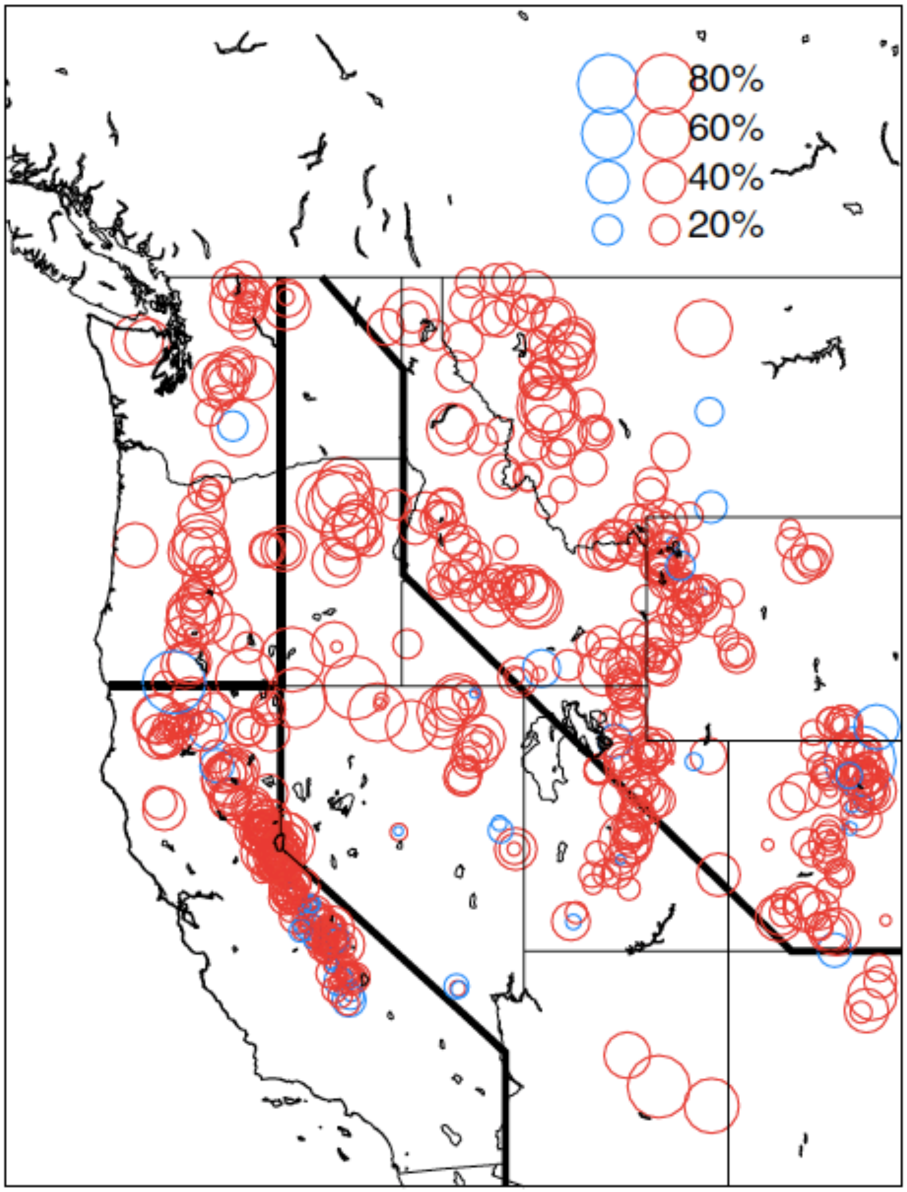

Figure 5. *Linear trend in April 1 snow water equivalent (SWE) relative to 1955, for the period 1955-2016. Negative trends (reduced snowpack) shown by red circles and positive trends (increasing snowpack) shown with blue circles. Larger circles represent greater amount of change. (Figure source: P. Mote, et al. 2018.)*

17. The implications for water availability in the western United States is stark. In this region, reduced snowpack due to warming is creating drought conditions and is making existing drought conditions much worse. As GHG emissions continue as they are today, these drought conditions will worsen, with ever more severe impacts in the immediate future.

18. **Figure 6** illustrates the change in the number of large fires in each ecoregion of the western United States between 1984 and 2011.[10] The black line in each graph describes the linear trend for that region. There is a statistically significant increase in the number of large fires in each region except the Snake Plain/Columbia Plateau, the Basin and Range, and Mediterranean California. According to the Climate Science Special Report published by the U.S. Global Change Research Program, changes in "climate drivers" have been "responsible for over half the observed increase in western U.S. forest fuel aridity from 1979 to 2015 and doubled the forest fire area over the period 1984-2015."[11]

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[10] Dennison PE, Brewer SC, Arnold JD, Moritz MA, 2014, Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters* 41(8): 2014GL059576.

[11] USGCRP, 2017, *Climate Science Special Report: Fourth National Climate Assessment, Volume I*, 243, https://science2017.globalchange.gov/.

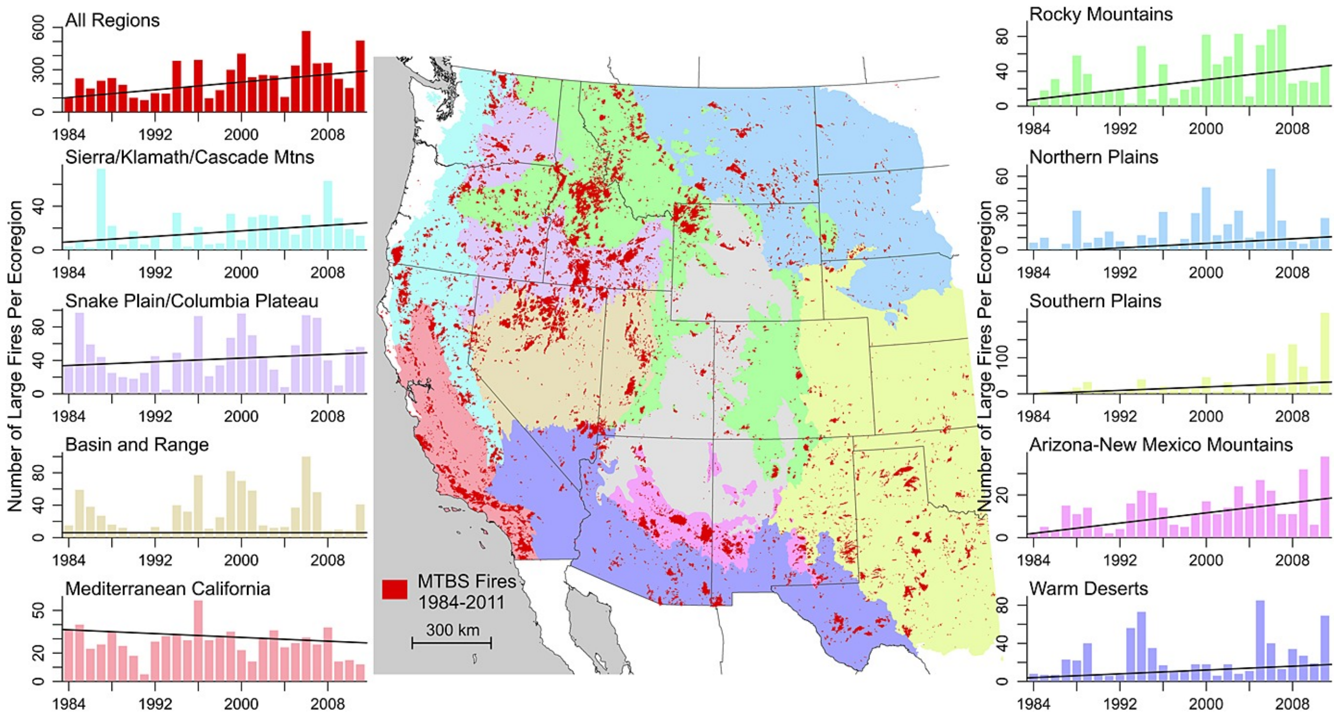

Figure 6. *Change in number of large fires in ecoregions of the western United States from 1984 – 2011 (Source: Dennision, et al. Large wildfire trends in the western United States, 1984-2011. Geophysical Research Letters. 2014)*

19. The real world implications of these aridification trends are irreparably harming the Youth Plaintiffs in this case. For example, based upon my review of the Declarations of Plaintiff Jaime Lynn, Jaime had to move from her home on the Navajo Reservation in Cameron to Flagstaff, Arizona because the springs they depended on for water were drying up and they were unable to sustain their farm and animals. It is clear that the pattern of drought in places like arid Arizona is directly linked to climate change.

20. Periodic droughts, such as the 5-year drought in California, combined with the current state of exceptional drought (the most intense definition of drought used by the federal government) in parts of Utah, Colorado, and Arizona, have reduced

the reservoir levels of Lakes Powell and Mead, the two biggest water storage facilities for the Colorado River that serve the desert Southwest.[12] As of February 2019, Lake Mead is at 39.54% of capacity,[13] and Lake Powell is now at 40.74% of full pool.[14] To refill Lakes Powell and Mead will require sustained river runoff in excess of human demand; it is likely that they will never refill completely again and, as discussed below, will cease being sources of drinking water. The Colorado River provides water for nearly 40 million people and agricultural users spread across the west from Los Angeles, California to Denver, Colorado. In large part due to decades of warming temperatures and associated drought, water demand has gone up while the rainfall and snowpack that supply the Colorado River and its reservoirs has dwindled.

21. In many areas of the Colorado River Basin, there have been record-low snowpack levels in 2018, making this the driest 19-year period on record.[15] With drought conditions dating back to 2000, this is one of the worst drought cycles over the last 1,200 years. Since 1982, the seasonal winter snowpack period of the

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[12] Barnett TP, Pierce DW, 2008, *When will Lake Mead go dry? Water Resources Res*. 44:W03201 doi:10.1029/2007WR006704.

[13] Lake Mead Water Database, Water Summary, http://lakemead.water-data.com/ (last visited Feb. 5, 2019).

[14] Lake Powell Water Database, Water Summary, http://lakepowell.water-data.com/ (last visited Feb, 5, 2019).

[15] U.S. Bureau of Reclamation, *Another Dry Year in the Colorado River Basin Increases the Need for Additional State and Federal Actions*, https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=62170 (last visited Feb. 5, 2019).

conterminous United States has declined on average 1 day per year, 34 days. The annual maximum snow mass in the mountains of the West has declined 41%.[16] Because of this drought cycle, experts predict that runoff from the Rocky Mountains into Lake Powell this spring will be only 42% of the long-term average.[17]

22. Beginning in 2020, models predict a 52% chance of water shortage conditions at Lake Mead, with a greater than 60% likelihood of shortage thereafter.[18]

23. In December 2018, federal water managers projected that the level in Lake Mead will drop sufficiently that mandatory water restrictions will be enacted.[19] Federal water managers set a January 31, 2019 deadline for Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming and the federal government to finalize "unprecedented voluntary drought contingency plans they expect to have to enact in 2020."[20]

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[16] Zeng, X., Broxton, P. and Dawson, N., 2018, Snowpack Change From 1982 to 2016 Over Conterminous United States. *Geophysical Research Letters*.

[17] U.S. Bureau of Reclamation, *Another Dry Year in the Colorado River Basin Increases the Need for Additional State and Federal Actions*, https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=62170 (last visited Feb. 5, 2019).

[18] U.S. Bureau of Reclamation, *Another Dry Year in the Colorado River Basin Increases the Need for Additional State and Federal Actions*, https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=62170 (last visited Feb. 5, 2019).

[19] Ken Ritter, *Seven Southwestern States, Including Utah, Expected to Sign a Colorado River Drought* Plan, The Salt Lake Tribune (Dec. 10, 2018), https://www.sltrib.com/news/nation-world/2018/12/09/us-states-meet-deadline/

[20] U.S. News and World Report, *The Latest: U.S. Sets Jan. 31 Deadline for Colorado River Plan* (Dec. 13, 2018), https://trib.com/news/state-and-regional/us-sets-jan-

24. The causes of the aridification of the West are not unknown. According to the 4th National Climate Assessment, "[w]ater for people and nature in the Southwest has declined during droughts, due in part to human-caused climate change . . . . In the ongoing Colorado River Basin drought, high temperatures due mainly to climate change have contributed to lower runoff and to 17%-50% of the record-setting streamflow reductions between 2000 and 2014."[21] Yet in spite of this knowledge, GHG emissions continue to be emitted in the United States at scientifically significant rates.

The Longer Wildfire Seasons and More Severe Wildfires Are Causing Plaintiffs' Irreparable Harm

25. Climate scientists have long known that increasing temperatures would increase drought conditions and the combination of drier and hotter weather would mean more frequent and severe wildfires. By 2006, scientists documented that the wildfire season in the western United States was 87 days longer than it was in the 1980s.[22] The number of large fires, >1000 acres, had grown four times, and the number of acres burned per year had increased six times.

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deadline-for-colorado-river-plan/article_6990f67e-d4b2-5d27-9b21-53c9a38a7fb3.html.

[21] USGCRP, 2018, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, https://nca2018.globalchange.gov/

[22] Westerling AL, Hidalgo HG, Cayan DR, Swetnam TW, 2006, Warming and earlier spring increase western US forest wildfire activity. *Science* 313: 940–943.

26. More recent studies have found the global wildfire season increased 19% globally from 1979–2013, and the global area vulnerable to wildfire increased 108%.[23] This will only worsen the impacts for the many Plaintiffs in the West who are suffering increased risk and severity of impacts from wildfires near their homes, in places that they visit for recreation, and in the air they breathe during the extended fire season, including Xiuhtezcatl, Jaime Lynn, Jacob, Sahara, Kelsey, Alex, Zealand, Nick, Aji, Nathan, Hazel, and Avery.

27. The lengthening of the fire season is largely due to declining mountain snowpack, earlier spring snowmelt, decreased summer precipitation, and warmer summer temperatures. In the Pacific Northwest, the fire season length increased over the last four decades, from 23 days in the 1970s, to 116 days in the 2000s.[24] Abatzoglou and Williams (2016) found that anthropogenic climate change from 1979–2015 added 55% to fuel aridity across western U.S. forests.[25] Dennison et al.

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[23] Jolly WM, Cochrane MA, Freeborn PH, Holden ZA, Brown TJ, Williamson GJ, Bowman DMJS, 2015, Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications* 6: 7537. DOI: 10.1038/ncomms8537

[24] Westerling AL, 2016, Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. *Phil. Trans. R. Soc. B* 371(1696): 20150178. DOI: 10.1098/rstb.2015.0178.

[25] Abatzoglou JT, Williams AP, 2016, Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences* 113(42): 11770–11775. DOI: 10.1073/pnas.1607171113.

(2014) found that, from 1984–2011, the area of fire scars, or burned area, was increasing 355 km^2/year in the western United States.[26]

28. Wildfire smoke is having a deleterious effect on the air that Plaintiffs breathe. Lack of access to clean air poses serious health risks, particularly for those Plaintiffs that are especially vulnerable to air pollution, including Alex, Isaac, Tia, Nick, Sahara, Nathan.

29. Acute health effects are documented from breathing smoky air in western cities, like the asthma attacks Plaintiff Sahara experiences. In the late summers of 2017 and 2018, wildfire smoke and ash shrouded the city of Seattle, where Plaintiff Aji lives,[27] and much of Western Oregon, where Plaintiffs Avery, Hazel, Sahara, Zealand, and Jacob live. This situation will only get worse as more GHG emissions are released.

30. The Congressional Research Service has recognized that "wildfires can damage timber resources and soils and degrade water quality and watershed functions. Wildfires can also damage communities, destroy homes, and lead to loss

[26] Dennison PE, Brewer SC, Arnold JD, Moritz MA, 2014, Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters* 41(8): 2014GL059576. DOI:10.1002/2014GL059576.
[27] Alan Blinder & Christina Caron, *Seattle Chokes as Wildfire Smoke from Canada Blankets the Northwest,* N.Y. TIMES, August 7, 2017, at https://www.nytimes.com/2017/08/07/us/wildfires-canada-seattle.html.

of human life."[28] NOAA's National Centers for Environmental Information reports that, in 2017, "66,131 fires (7th least since 2000) burned 9,781,062 acres (3rd most on record), which is 147.9 acres burned/fire (2nd most on record)."[29] For example, in late summer 2017, wildfires devastated many communities in Northern California, causing significant loss of property, including the mobile home park where Plaintiff Zealand's grandmother lived and where Zealand spent many winter holidays.

31. The National Interagency Fire Center reported federal expenditures for wildfire fighting at $2.918 billion in 2017, the highest on record.[30] NOAA has tracked billion dollar plus weather and climate disasters in the U.S. for many years. According to NOAA's National Centers for Environmental Information:

> *During 2017, the U.S. experienced a historic year of weather and climate disasters. In total, the U.S. was impacted by 16 separate billion-dollar disaster events tying 2011 for the record number of billion-dollar disasters for an entire calendar year. In fact, 2017 arguably has more events than 2011 given that our analysis traditionally counts all U.S. billion-dollar wildfires, as regional-scale, seasonal events, not as multiple isolated events.*
>
> *More notable than the high frequency of these events is the cumulative cost, which exceeds $300 billion in 2017 — a new U.S. annual record. The cumulative damage of these 16 U.S. events during 2017 is $306.2 billion, which shatters the previous U.S. annual record cost of $214.8*

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[28] Hoover, K., Congressional Research Service. 2017. Wildfire Management Funding: Background, Issues, and FY 2918 Appropriations, at https://fas.org/sgp/crs/misc/R45005.pdf.

[29] NOAA, NCDC. Wildfires – Annual 2017. https://www.ncdc.noaa.gov/sotc/fire/201713.

[30] National Interagency Fire Center. Federal Firefighting Costs (Suppression Only), https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf (last visited Feb. 5, 2019).

> *billion (CPI-adjusted), established in 2005 due to the impacts of Hurricanes Dennis, Katrina, Rita and Wilma.*[31]

32. NOAA specifically described the "Western Wildfires" and "California Firestorm" that occurred in 2017:

> *A historic firestorm damages or destroys over 15,000 homes, businesses and other structures across California in October. The combined destruction of the Tubbs, Atlas, Nuns and Redwood Valley wildfires represent the most costly wildfire event on record, also causing 44 deaths. Extreme wildfire conditions in early December also burned hundreds of homes in Los Angeles. Numerous other wildfires across many western and northwestern states burn over 9.8 million acres exceeding the 10-year annual average of 6.5 million acres. Montana in particular was affected by wildfires that burned in excess of 1 million acres. These wildfire conditions were enhanced by the preceding drought conditions in several states.*[32]

33. In Fall 2018, California experienced the most deadly and destructive wildfires in state history. Approximately 8,572 fires burned more than 1.8 million acres resulting in over $3.5 billion in damages, driving $1.8 billion in fire suppression costs, and killing more than 100 people. The 2018 Mendocino Fire Complex was California's largest wildfire on record, burning 459,123 acres which is more than 60% larger than any prior wildfire.[33]

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[31] NOAA, National Centers for Environmental Information. *Billion-Dollar Weather and Climate Disasters: Overview*, https://www.ncdc.noaa.gov/billions/ (last visited Feb. 5, 2019).

[32] NOAA, National Centers for Environmental Information. *Billion-Dollar Weather and Climate Disasters: Table of Events.* https://www.ncdc.noaa.gov/billions/events/US/1980-2017 (last visited Feb. 5, 2019).

[33] California Dep't of Forestry and Fire Protection, *Top 20 Largest California Wildfires*,

34. The 2018 Camp Fire that burned in November 2018 was the deadliest and most destructive wildfire in California state history, completing destroying the town of Paradise.[34]

35. On November 30, 2018, Former Secretary of Interior Ryan Zinke announced that the 2018 wildfire season in California "is estimated to have released emissions equivalent to roughly 68 million tons of carbon dioxide. This number equates to about 15 percent of all California emissions, and it is on par with the annual emissions produced by generating enough electricity to power the entire state for a year. The recent Camp and Woolsey fires have produced emissions equivalent to roughly 5.5 million tons of carbon dioxide."[35] The increased severity and size of fires poses another dangerous feedback loop in the climate system by increasing the amount of greenhouse gas emissions released into the atmosphere.

36. The severity of this fire season, and in particular the extreme late-season fires occurring in both the Northern and Southern parts of the California simultaneously, is a result of conditions that are directly attributable to the warming of the climate,

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https://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Acres.pdf (last visited Feb. 5, 2019).

[34] NASA Earth Observatory, *Camp Fire Adds Another Scar to 2018 Fire Season*, https://earthobservatory.nasa.gov/images/144300/camp-fire-adds-another-scar-to-2018-fire-season (last visited Feb. 5, 2019).

[35] U.S. Dep't of Interior, *New Analysis Shows 2018 California Wildfires Emitted as Much Carbon Dioxide as an Entire Year's Worth of Electricity*, https://www.doi.gov/pressreleases/new-analysis-shows-2018-california-wildfires-emitted-much-carbon-dioxide-entire-years (last visited Feb. 5, 2019).

including increased winter temperatures, hotter summer temperatures, multi-year drought, longer growing seasons, and an extended season of fire weather. The bone-dry vegetation and high temperatures and wind combine to make fire spread from any ignition source to be so fast that humans can no longer control the blazes. Without immediate and significant actions to reduce greenhouse gas emissions by Defendants, global temperatures will continue to increase and exacerbate these conditions. The magnitude of wildfire that destroyed Paradise, is a harbinger of destruction to come in the West.

Climate Change Projections Underscore the Irreparability of the Harm Plaintiffs' Face

37. The irreparable harms discussed above are those that Plaintiffs are presently experiencing. It is worth noting that future projections of climate and ecosystem impacts for the United States are even more devastating. This is important because of the long-lived nature of CO_2 emissions in the atmosphere, as discussed above. As global emissions continue to rise, all global climate models project higher temperatures in the coming decades. At current emission levels, temperatures in the Pacific Northwest could rise 10 degrees Fahrenheit. A 10° F increase in temperatures would result in extreme and irreversible harm to terrestrial ecosystems, leading to more extreme weather events, species extinctions, and sea level rise inundating major coastal cities worldwide. The resulting harms to human society will also be substantial and would include disruption of agricultural production, famine, disease

and climate refugees fleeing uninhabitable countries generating ongoing immigration crises. Tropical diseases and invasive pests are already moving north and this trend will accelerate. A 10°F temperature increase by the end of this century will virtually eliminate the winter snowpack and will at least quadruple our wildfires.

38. The only way to avoid the worst-case projected impacts is to begin reducing GHG emissions today.

39. Scientists predict that if emissions continue as they are today, 34%-53% of the western United States that receives snowfall will change to winter rainfall and that the seasonal period of annual snowcover in the West will drop from 5 months to 3 months. For example, I have predicted in a published study that Spring snowmelt at West Glacier, Montana which began averaging April 8th in 1950, will begin on February 25 by 2089, which will finally spell the end of glaciers in Glacier National Park.

40. By 2050, the SWE in snowpack in the Pacific Northwest will decline 30% more and by 2100 by 50%.[36] The ramifications of this transition would be severe.

41. These projections of future risk are not speculative. While scientists do not have a crystal ball to predict the future, the impacts we are already seeing with the

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[36] OCAR, 2017, *The Third Oregon Climate Assessment Report*, Oregon Climate Change Research Institute, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR. http://www.occri.net/media/1042/ocar3_final_125_web.pdf.

warming that has happened today provide clear support for the notion that the projected risks will be devastating.

Urgent and Rapid Reductions of U.S. GHG Emissions are Needed to Prevent Irreparable Harm to the Plaintiffs

42. If humanity reduces CO_2 emissions significantly in the near-term, the increase in global temperatures could be kept to 1.3-1.5°C in the short-term, stabilizing at 1°C by the end of the century. Any additional increase in global temperatures will cause substantial changes to global terrestrial ecosystems.

43. Reducing CO_2 emissions reduces CO_2 emissions in the atmosphere proportionally, which reduces temperature increases proportionally.

44. In my expert opinion, it is not too late to take action to slow and eventually halt climate change, but we are on the brink of being too late. The more GHG emissions that are emitted into the atmosphere, the more unlikely it is that mitigation efforts can be implemented quickly enough to avoid the devastating climate change impacts that are projected to occur.

45. It is important to emphasize that it is the status quo of business as usual GHG emissions that is causing additional irreparable harm to Plaintiffs *today*, on top of harms they already experience from past emissions accumulated in the atmosphere and oceans. While that harm is projected to get worse and more irreversible if GHG emissions continue, the only way to prevent Plaintiffs' injuries in the short and long

term is to alter the rate at which GHGs are emitted in the United States and worldwide.

46. It is critical that action by Defendants to reduce CO_2 emissions occur immediately. The federal government has for many years had knowledge, information, and scientific recommendations that it needed to transition the Nation off of fossil fuels in order to first prevent against, and now try to stop, catastrophic climate change. We are well beyond the maxim: "If you find yourself in a hole, quit digging."

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct. Executed on February 5, 2019.

Respectfully submitted,

Steven W. Running

Exhibit 1

SUPPLEMENTAL EXPERT REPORT
OF
STEVEN W. RUNNING, Ph.D.

University Regents Professor Emeritus of Global Ecology
University of Montana, Missoula

Kelsey Cascadia Rose Juliana; Xiuhtezcatl Tonatiuh M.,
through his Guardian Tamara Roske-Martinez; et al.,
Plaintiffs,

v.

The United States of America; Donald Trump,
in his official capacity as President of the United States; et al.,
Defendants.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF OREGON

(Case No.: 6:15-cv-01517-TC)

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TABLE OF ACRONYMS AND ABBREVIATIONS

BAU:	business as usual
C:	Celsius
CMIP:	Coupled Model Intercomparison Project
CO_2:	carbon dioxide
CPI:	Consumer Price Index
EOS:	Earth Observing System
F:	Fahrenheit
GCM:	general climate model
GHG:	greenhouse gas
IPCC:	Intergovernmental Panel on Climate Change
m:	meter
NASA:	National Aeronautics and Atmospheric Administration
NCA:	National Climate Assessment
NOAA:	National Oceanic and Atmospheric Administration
NTSG:	Numerical Terradynamic Simulation Group
ppm:	parts per million
PM2.5:	particulate matter 2.5
RCP:	representative concentration pathways
SERS:	Special Report on Emissions Scenarios
SLR:	sea level rise
SWE:	snow water equivalent
SWIPA:	Snow, Water, Ice and Permafrost in the Arctic
SWR:	snow water equivalent

INTRODUCTION

I, Steven W. Running, have been retained by Plaintiffs in the above-captioned matter to provide expert testimony regarding how human-caused CO_2 emissions are harming terrestrial ecosystems, human communities, and the Plaintiffs themselves. I will discuss projections for the future should emissions continue on a business as usual (BAU) course and the means of preventing the worst of the impacts we project throughout the century.

I received my Ph.D. (1979) in Forest Ecology from Colorado State University. Since 1979, I have been with the University of Montana, where I retired in 2017 and now am a University Regents Professor Emeritus of Global Ecology in the College of Forestry and Conservation. I founded the Numerical Terradynamic Simulation Group (NTSG) at the University of Montana in 1983. My primary area of research is the development of global and regional ecosystem biogeochemical models integrating remote sensing with bioclimatology and terrestrial ecology. I am a Team Member for the NASA Earth Observing System (EOS), Moderate Resolution Imaging Spectroradiometer, and I am responsible for the EOS global terrestrial net primary production and evapotranspiration datasets.

I have published over 300 scientific articles and two books, and have been honored with several awards, including the E.O. Wilson Biodiversity Technology Pioneer Award, and the W.T. Pecora award for lifetime achievement in Earth remote sensing from NASA and US Geological Survey. I have served on the standing Committee for Earth Studies of the National Research Council and on the federal Interagency Carbon Cycle Science Committee. I have also served as a Co-Chair of the National Center for Atmospheric Research Community Climate System Model Land Working Group, a Member of the International Geosphere-Biosphere Program Executive Committee, and the World Climate Research Program, Global Terrestrial Observing System. I just completed serving on the advisory NASA Earth Science Subcommittee, and the NOAA Science Advisory Board Climate Working Group.

In 2007 I shared the Nobel Peace Prize as a chapter Lead Author for the 4th Assessment of the Intergovernmental Panel on Climate Change (IPCC). I am an elected Fellow of the American Geophysical Union and am designated a Highly Cited Researcher by the Institute for Scientific Information.

The opinions expressed in this report are my own, and not the opinions of any of the institutions for which I work or donate my time. The opinions expressed herein are based on the data and facts available to me at the time of writing and are to a reasonable degree of scientific certainty, unless otherwise specifically stated. Should additional relevant or pertinent information become available, I reserve the right to supplement the discussion and findings in this expert report in this action.

My CV is contained in **Exhibit A** to my expert report in this action. A list of publications I authored within the last ten years is attached as **Exhibit B** to my expert report. A statement of my previous testimony within the preceding four years as an expert at trial or by deposition is contained in **Exhibit C** to my expert report.

In preparing this report, I have reviewed a number of documents. My report contains a list of citations to the documents that I have used or considered in forming my opinions, listed in **Exhibit D**. In particular, the most definitive summaries of the scientific information that formed the basis of my opinions are the IPCC reports, and I reviewed the most recent report, the 5th, published in 2013. It is important to note that while the IPCC is an important resource, the extensive pre-publication review often results in rather conservative conclusions. It has often underestimated the most dangerous climate change risks within projections. I also read the US National Climate Assessment of 2014, of which I was a lead author of the Forests chapter. On impacts to the Pacific Northwest, I read Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. (Litell et al. 2013). Most recently I reviewed the Arctic Monitoring and Assessment Program's 2017 Snow, Water, Ice and Permafrost in the Arctic (SWIPA) Assessment Summary for Policy-makers, published in April, 2017, and the 4th National Climate Assessment, titled "Climate Science Special Report" (USGCRP 2017).

Also attached hereto are **Exhibits E–G**, time-lapse series and accompanying documentation, which support my expert opinion on the effects of climate change on insect epidemics in forests.

In preparing my expert report and testifying at trial, I am not receiving any compensation and am providing my expertise pro bono to the Plaintiffs given the financial circumstances of these young Plaintiffs.

EXECUTIVE SUMMARY

The Federal Defendants and their predecessors have been actively studying human-induced climate change since the 1950s, although scientists have been researching and publishing on the greenhouse effect from burning fossil fuels throughout the early 1900s as well. Due to the Federal Government's mounting concerns about climate change, the Energy Security Act of 1980 triggered a host of scientific reports on the future and potential impact of carbon emissions on global climate. Since then, the Federal Government has been convening formal scientific reports on global warming by the National Research Council, the Department of Energy, the Environmental Protection Agency, the interagency US Global Change Research Program and others.

Beginning in 1981, I was part of the NASA planning for Mission to Planet Earth that resulted in building and deploying the Earth Observing System that to this day provides key global change datasets (NASA 1983). It is remarkable that in these 1980-1983 reports, many of the main impacts of climate change, sea level rise, ice sheet melting, glacial retreat, droughts and floods, agricultural and ecosystem disruption were already identified and expected. It is poignant that the Federal Defendants were concerned about atmospheric CO_2 having already risen to 340 ppm and the dangers associated with even that rise. It is now fluctuating around 407–410 ppm.

The Federal Defendants fully acknowledge this history of active and open enquiry on future global climate instability, and these reports laid the strategic foundation for climate and carbon cycle science ever since then. Many of the specific climate science questions these committees posed in 1980 have long been answered and unequivocally conclude that the burning of fossil fuels is a central cause of climate change. A more difficult challenge for the scientific community has been to monitor comprehensively how these emerging climate trends are impacting, and will impact, the biosphere with the multiple complexities and interactions of ecosystems. This expert report documents some of the impacts on terrestrial ecosystems already evident. Projecting the rate of future impacts, and identifying potentials for possible ecosystem collapse are topics of ongoing research, but we are able to look at current trends to conclude that if BAU emissions continue, or if emissions are only slightly reduced, the future impacts will be severe.

The influence of the increase of greenhouse gases in the atmosphere brought on by burning fossil fuels was predicted in 1896, when atmospheric CO_2 levels were ~280 ppm, and is now well underway. Atmospheric CO_2 is now at ~407–410 ppm with regional and seasonal variation, and increasing about 2 ppm/year. The resulting increase in global air temperatures is now well documented at almost 1° Celsius (C) above preindustrial temperatures and rising. Impacts of the global warming trend are already measureable in the western United States. This report summarizes hydrologic and ecological impacts in the western United States, with added emphasis on the Pacific Northwest and Colorado where many of the Plaintiffs live and recreate. These impacts pose an unusually serious risk of harm to youth Plaintiffs and future generations.

1. As an overall summary, in the last 50 years, winter has become two weeks shorter, and summer two weeks longer in the western United States. By mid-century general climate model (GCM) projections state that winter will be two additional weeks shorter, and that trend will continue at least until the end of the century.
2. Spring snowmelt begins two weeks earlier than 50 years ago, and spring riverflow peaks are likewise earlier.
3. The lowest streamflows in late summer are now 20–30% lower than historic periods. These exceptional low waterflows increase water temperatures to lethal levels for coldwater fish like trout and salmon. Warmer water also retains less dissolved oxygen for aquatic species.
4. With longer summer periods, that are also hotter in the West, the wildfire season is 2–3 months longer than 40 years ago. Biomass fuels dry to combustible levels at higher elevations that used to have snowcover until July, and fuels at all elevations are drier because of higher atmospheric evaporation.
5. The longer, more active wildfire season is producing public health problems from smoke and particulate inhalation and is causing significant property loss.
6. The longer drier summers are dehydrating and stressing forests, which are now succumbing to epic insect outbreaks and forest mortality over 12 states.
7. The overwintering survival of insect larvae has increased substantially, allowing the beetle populations to expand more quickly than before.
8. Climate and particularly snow-sensitive wildlife are becoming more vulnerable to predation and nesting failure. As the duration of snowcover continues to shrink, these animals become phenologically mismatched with their habitat.
9. Recreational opportunities for winter sports are declining in pace with declining snowcover.

Future projections of increasing atmospheric CO_2 will continue the geographic expanse and severity of these negative impact trends for the foreseeable future, absent immediate efforts to drastically reduce GHG emissions.

EXPERT OPINION

PART A: ANALYSIS OF DIRECT MEASUREMENTS

1. Anthropogenic CO_2 emissions with other GHGs are causing warming of Earth's surface and climate change.

In 1896, Svant Arrhenius, a Swedish chemist, understanding the basic physics of how molecules like CO_2 differentially transmit shortwave solar radiation, but absorb longwave thermal radiation, postulated that the then new practice of burning fossil fuels emitting CO_2 could one day warm the global atmosphere. In 1958, Dr. David Keeling began the modern monitoring of atmospheric CO_2 at Mauna Loa, Hawaii, a remote location not near any local CO_2 sources. As Arrhenius postulated, the monitoring data proved that CO_2 has continued to rise every year from 1958 to the present from an initial concentration of 316 ppm in 1958, to an annual average level of 407 ppm in 2017 (Figure 1).

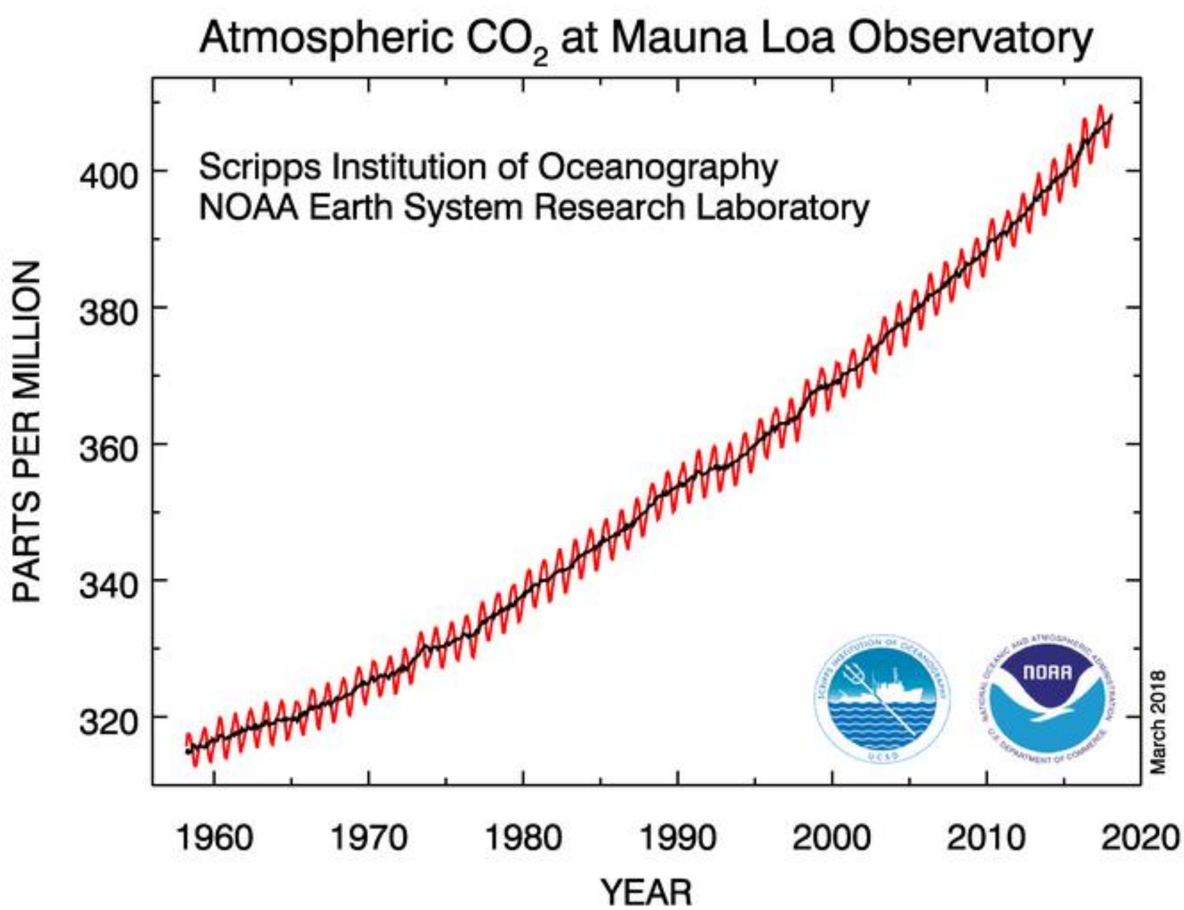

Figure 1. *Atmospheric CO_2 concentration measured at Mauna Loa observatory from 1958 to the present.* (https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html).

The Mauna Loa measurements are now replicated at dozens of stations worldwide, all of which confirm the growing CO_2 concentrations, and the global average CO_2 for 2017 was 407 ppm.

The continuous rise in atmospheric CO_2 has in fact caused global, and national air temperatures to rise, as measured by US weather stations. The 2017 National Climate Assessment (USGCRP 2017) found that global air temperatures had risen by 1.8° F since 1901. It is irrefutable and well known for over ten decades that as CO_2 concentrations increase, the surface of the planet warms and the oceans warm. That global warming causes climate change and has many harmful effects on ecosystems and humans is discussed below. It is as if the Earth has a constant fever, and just as in the human body, even a slight rise in temperature weakens the organism, increases vulnerability of the organism, and can have dangerous long-term effects on the system.

2. Annual and seasonal temperature averages have changed globally and in the United States as a result of climate change.

Since 1960, global average air temperature has shown a progressive increase in temperatures (Figure 2). To quote from the official climate website of the Federal Defendant Department of Commerce's National Oceanic and Atmospheric Administration (NOAA):

> *The monthly global land and ocean temperatures at the start of 2017 were extremely warm, with the first four months each ranking as the second warmest for their respective months, behind the record year 2016. Of particular note, the global land and ocean temperature for the month of March 2017 was 1.03°C (1.9°F) above the 20th century average—this marked the first time the monthly temperature departure from average surpassed 1.0°C (1.8°F) in the absence of an El Niño episode in the tropical Pacific Ocean. After reaching its peak monthly temperature departure from average in March, temperatures began to slowly decrease in magnitude, ranging between +0.73°C to +0.88°C (+1.31°F to +1.58°F). The last four months each ranked among the four warmest on record, giving way to 2017 becoming the third warmest year in NOAA's 138-year record. The 2017 average global temperature across land and ocean surface areas was 0.84°C (1.51°F) above the 20th century average of 13.9°C (57.0°F), behind the record year 2016 (+0.94°C / +1.69°F) and 2015 (+0.90°C / +1.62°F; second warmest year on record) both influenced by a strong El Niño episode. The year 2017 is also the warmest year without an El Niño present in the tropical Pacific Ocean.*
>
> *2017 also marks the 41st consecutive year (since 1977) with global land and ocean temperatures at least nominally above the 20th century average, with the six warmest years on record occurring since 2010. Since the start of the 21st century, the global temperature has been broken five times, three of those being set back to back (2014–2016). The yearly global land and ocean temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880; however, the average rate of increase is twice as great since 1980. From 1900 to 1980 a*

new temperature record was set on average every 13.5 years; however, since 1981 it has increased to every 3 years.[1]

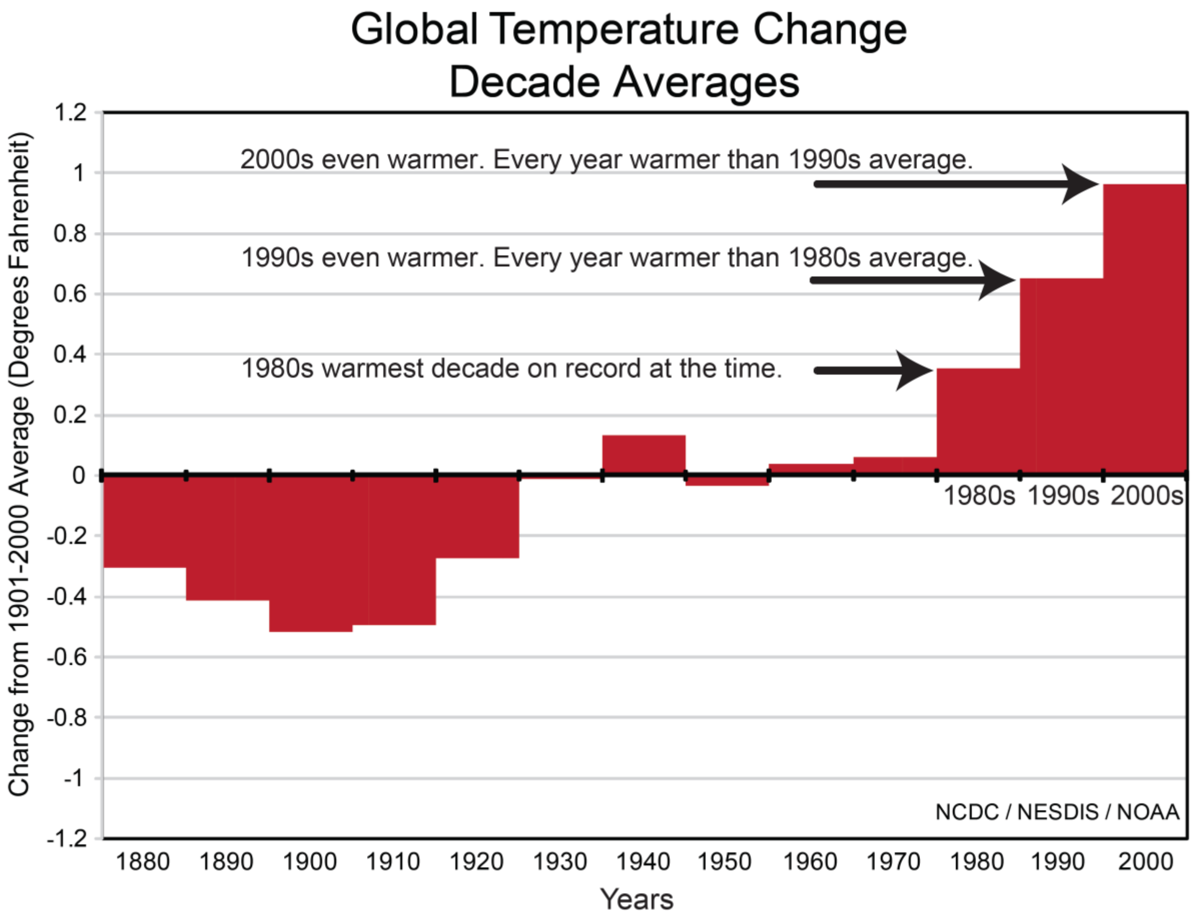

Figure 2. *Global temperature changes aggregated decadaly. (NCDC/NESDS/NOAA).*

The US 4th National Climate Assessment (USGCRP 2017) has summarized the trend in temperatures and precipitation since 1895. (Figures 3 and 4). It is important to note that in the arid West, even though precipitation has increased in some regions somewhat over the last century, temperatures and atmospheric evaporation have increased even faster. Hence, much of the West is slowly drying out. For example, based upon my review of the statements of Plaintiff Jaime Lynn, Jaime had to move from her home on the Navajo Reservation in Cameron to Flagstaff, Arizona because the springs they depended on for water were drying up and they were unable to sustain their farm and animals. That pattern of drought in places like arid Arizona is directly linked to climate change. Similarly, based upon my review of the statements of Plaintiffs Alex and Jacob, they both have family farms outside of Roseburg, Oregon and are regularly threatened with drought, increased heat and wildfires, making farming conditions more

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[1] NOAA, Global Climate Report – Annual 2017, Global Temperatures at https://www.ncdc.noaa.gov/sotc/global/201713.

challenging. The increasing severity of drought conditions in Oregon are a direct function of climate change.

Figures 3 and 4 summarize the trends in temperature and precipitation recorded at the nation's weather stations over the last century, compiled for the 4th National Climate Assessment (USGCRP 2017).

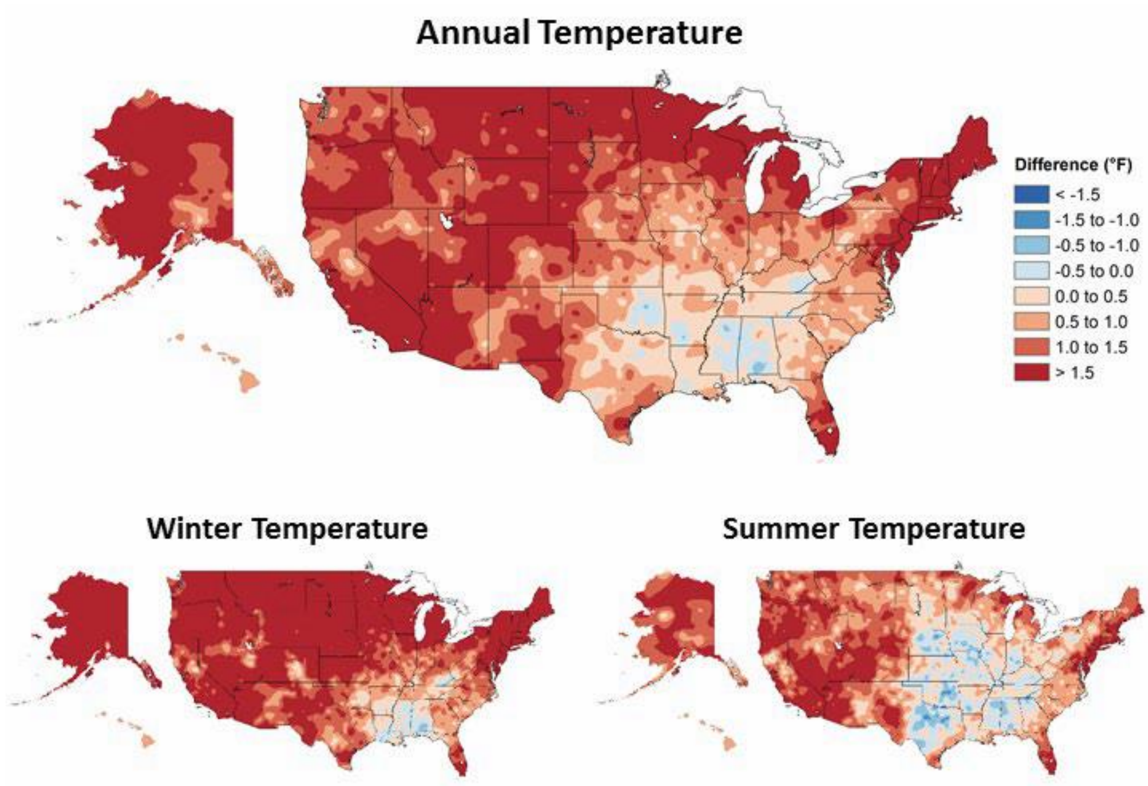

Figure 3. *Trend in weather station air temperatures from 1901–2016. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i). Estimates are derived from the nClimDiv dataset.1, 2 (Figure source: NOAA/NCEI). (USGCRP 2017).*

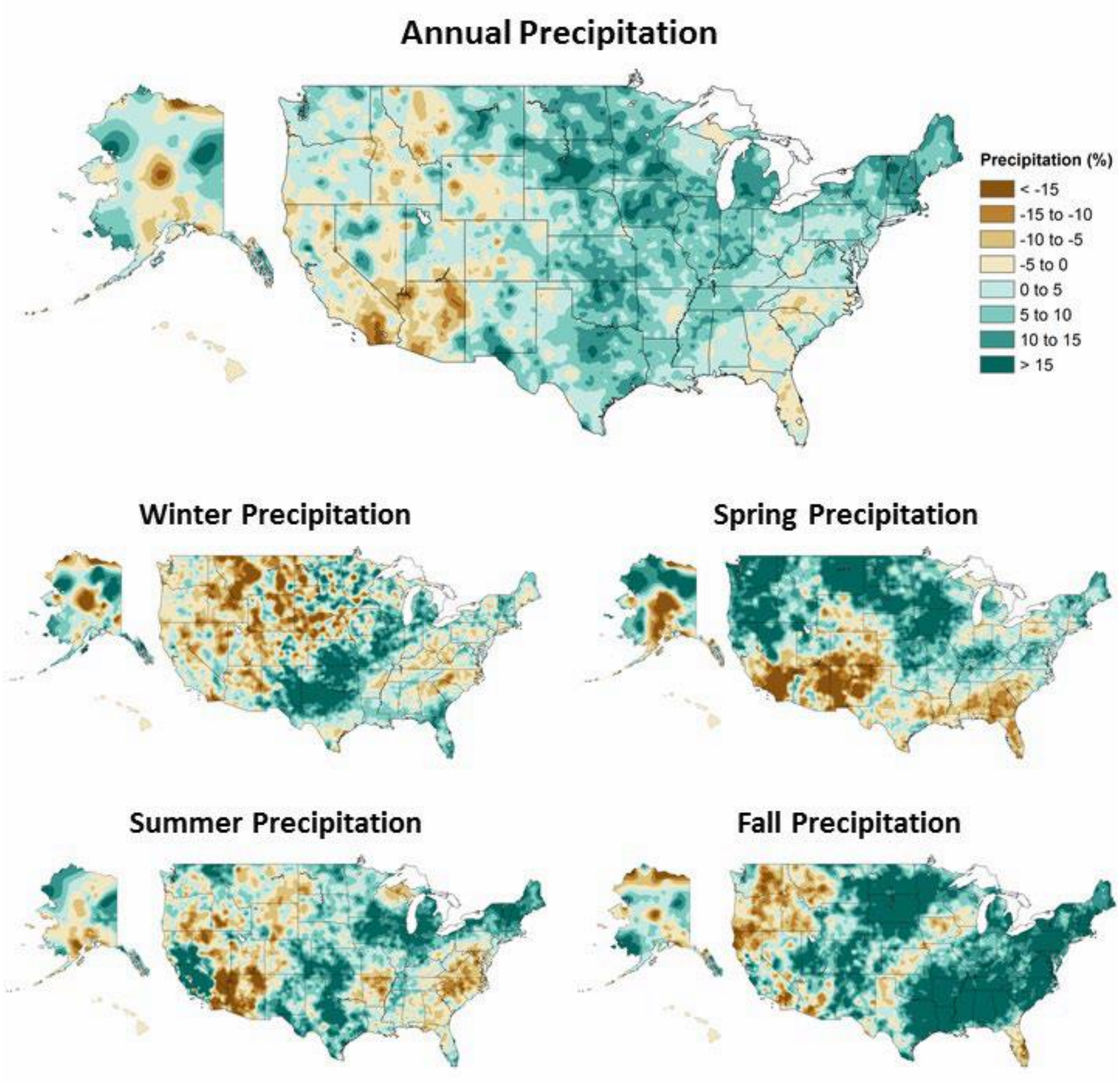

Figure 4. *Trends in weather station precipitation from 1901–2016. Annual and seasonal changes in precipitation over the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Figure source: [top panel] adapted from Peterson et al. 2013,78 © American Meteorological Society. Used with permission; [bottom four panels] NOAA NCEI, data source: nCLIMDiv]. (USGCRP 2017).*

John Wesley Powell, in the 1860s observed that western ecosystems, which I define as west of the 100th meridian, are fundamentally water limited, with potential evaporation exceeding actual rain and snowfall by 1–5m/yr, and climate change is increasing these water deficits. Much of the Western United States relies on snowpacks that accumulate over 4–6 months in the winter to melt in the spring and provide water through the summertime, where unlike in the Eastern United States, rather little rain falls. Although there is regional and interannual variability, as a simple regional summary, on average the winter is now two weeks shorter and the summer two weeks longer than 50 years ago. Projections are that by mid-century we will see another two weeks shorter winter and longer summer. That change brings significant ecological consequences (Figure 5).

a. Reduced snowpack and reduced summer flows in rivers

The NCA 2014 found that winter snowpacks across the northern tier of the country begin melting on average 14 days earlier than in 1950. Winter snowpacks are also far less dependable at lower elevations because of the higher mean temperatures, which lead to more days above the freezing level and more winter rain events than during the prior century. Boisvenue and Running (2010) found that Boise Idaho, at 857m elevation, and Missoula, MT, 1042m elevation, by the end of this century will not have sustained winter snowpacks.

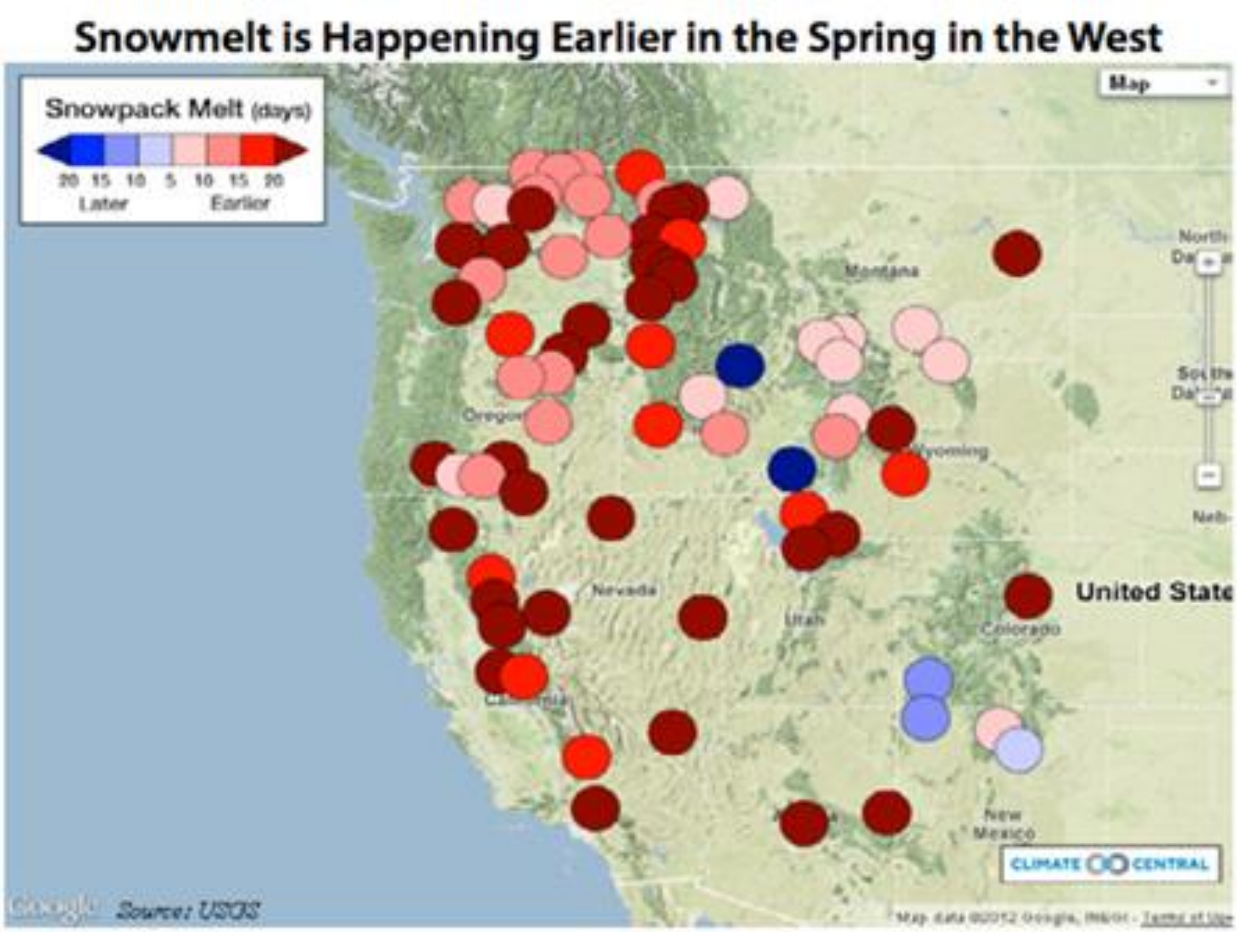

Figure 5. *Shift in calendar date that spring snowmelt commences. (Data from Barnett et al. (2008) and Mote et al (2005), graphed by Climate Central.* http://www.climatecentral.org/).

One immediate consequence of this trend is shortening the winter sports recreation season for skiing, ice fishing, snowmobiling, etc. Ski areas like Hoodoo Pass and Willamette Pass in Oregon, where Plaintiff Zealand recreates and his family has been employed, and Stevens Pass in Washington, where Plaintiff Aji recreates, have recently had years with so little snow the areas could not even open for business. In contrast, in the 1960s when I skied at Stevens Pass and

Snoqualmie Pass in Washington as a high school student, the snowpack was regularly above the top of the school bus. Some lower elevation ski areas, like Marshall Mountain in Montana, have simply gone out of business because snowcover was so undependable.

The Oregon Climate Assessment Report (OCAR 2017) documented some important impacts of low snowpack from the summer of 2015 that are harbingers of future climate impacts.

> *In 2015, Oregon was the warmest it has ever been since record keeping began in 1895. (NOAA, 2017). Precipitation during the winter of that year was near normal, but winter temperatures that were 5–6°F above average caused the precipitation that did fall to fall as rain instead of snow, reducing mountain snowpack accumulation (Mote et al., 2016). This resulted in record low snowpack across the state, earning official drought declarations for 25 of Oregon's 36 counties. . . . Drought impacts across Oregon were widespread and diverse:*
>
> > *• Farmers in eastern Oregon's Treasure Valley received a third of their normal irrigation water because the Owyhee reservoir received inadequate supply for the third year in a row (Stevenson, 2016).*
> > *• The 2015 fire season was the most severe in the Pacific Northwest's recorded history with more than $560 million in fire suppression costs (Sexton et al., 2016).*
> > *• After not opening at all in 2014, Mount Ashland Ski Area had to make snow in order to open in 2015 (Stevenson, 2016).*
> > *• Detroit Lake saw a 26% decrease in visitation due to low water levels and unusable boat ramps (Wisler, 2016).*
> > *• People near the Upper Klamath Lake were warned not to touch the water as algal blooms that thrived in the low flows and warm waters produced extremely high toxin levels (Marris, 2015).*
> > *• More than half of the spring spawning salmon in the Columbia River perished, likely due to a disease that thrived in the unusually warm waters (Fears, 2015).*
> > *• In Washington, the 2015 snow drought resulted in crop losses amounting to an estimated $212.4 million for wheat, $86.5 million for apples, $13.9 million for raspberries, and $10.6 million for blueberries (McLain and Hancock, 2015).*
>
> ***
>
> *Oregon's temperatures, precipitation, and snowpack in 2015 are illustrative of conditions that, according to climate model projections, may be considered "normal" by mid-century. With continued warming, this type of drought in which snowpack is low, but precipitation is near normal, should be expected more often in the future. In fact, for each 1.8°F of warming, peak snow water equivalent in the Cascade Range can be expected to decline 22%–30% (Cooper et al., 2016). The 2015 drought in Oregon provided a salient test on the capacity of existing*

> *systems to tolerate such drought and gave insights into potential future adaptation priorities.*[2]

Spring river runoff is occurring about two weeks earlier across the western U.S. compared to the 1950s, and now is often occurring before the water is needed for crop irrigation. Mean annual streamflow across the Pacific Northwest has decreased between the mid-20th century and the early-21st century, with the greatest decreases in summer (McCabe and Wolock 2014; Sagarika et al. 2014, OCAR 2017). More damaging is that the late summer lowest river flows are now frequently becoming dangerously low, causing drops in dissolved oxygen in the water and increased water temperatures that hurt trout and salmon populations. High stream temperatures will continue to impair the ability of anglers, including Jacob and Alex, to fish for recreation and consumption on local rivers due to impacts to the health of fisheries. This will also impair the ability of Avery and Hazel to watch and enjoy salmon in their local rivers in Eugene, Oregon. Leppi et al. (2008) found that 89% of rivers of Montana show declines in seasonal low flows in August in the period 1950–2008. The August flowrates in these Montana rivers now average 23% lower than in the 1960s (Leppi et al. 2008).

As an example, periodic droughts, such as the 5-year drought in California, have reduced the reservoir levels of Lakes Powell and Mead, the two biggest water storage facilities for the Colorado River that serve the desert Southwest (Barnett and Pierce 2008). As of March 2018, Lake Mead is at 41.33% of capacity,[3] and Lake Powell is now at 53.48% of full pool.[4] To refill them will require sustained river runoff in excess of human demand; it is likely that they will never refill completely again.

b. Aquatic habitat impacts

Sustained stream temperatures above 68°F are lethal to cold-water fish like trout and salmon, and can occur with declining snowpack and warmer summers (OCAR 2017, Service 2015). In the interior Columbia River Basin (largely in Idaho and western Montana), suitable bull trout habitat is projected to decline about 90% by the 2080s compared with present suitable habitat area (Kovich et al. 2015, Wenger et al. 2013). Migration timing for smolts getting ready to migrate to the ocean could be desynchronized by earlier peak streamflow timing from earlier melting of the snowpack (Wainwright and Weitkamp 2013). During the last sixty years, streamflow variability increased and, compared with other environmental changes, had the largest negative effect on Chinook salmon populations in the Northwest (Ward et al. 2015), which negatively affects Plaintiffs Avery's and Hazel's ability to watch salmon spawning in creeks in Oregon.

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[2] Oregon Climate Change Research Institute. 2017. The Third Oregon Climate Assessment Report, at 13. http://www.occri.net/media/1042/ocar3_final_125_web.pdf.

[3] Lake Mead Water Database, Water Summary, http://lakemead.water-data.com/ (last visited Mar. 27, 2018).

[4] Lake Powell Water Database, Water Summary, http://lakepowell.water-data.com/ (last visited Mar. 27, 2018).

3. Terrestrial ecosystem impacts already measured due to accelerating disturbances from climate change.

Climate change is already showing complicated impacts on western ecosystems due to the multiple non-linear interacting processes that govern ecosystem function. Running and Nemani (1991) illustrated how it is possible for western evergreen forests to grow faster, yet still endure more summer water stress, and then ultimately die from accelerated disturbance rates. Reeves et al. (2014) project a complicated response for western rangelands, with some increasing growth while others decrease. While John Wesley Powell in 1860 characterized the climatic aridity of the West, a functional relationship between the land water balance and ecosystem structure and function was first defined by Grier and Running (1977). They showed that precipitation itself is not the key driver of western ecosystems, but the net water balance between input precipitation and the output of atmospheric evaporative demand. Ecosystems grow in a dynamic equilibrium with the prevailing land water balance, and when that water balance declines, the ecosystem, and the individual plants become stressed. Plant water stress is conceptually similar to human dehydration. A dehydrated organism is weakened, less able to fight off attacks, and if the dehydration lasts long enough, the organism, whether plant or human, dies. Western ecosystems are already withstanding an acceleration of disturbance rates (Figure 6).

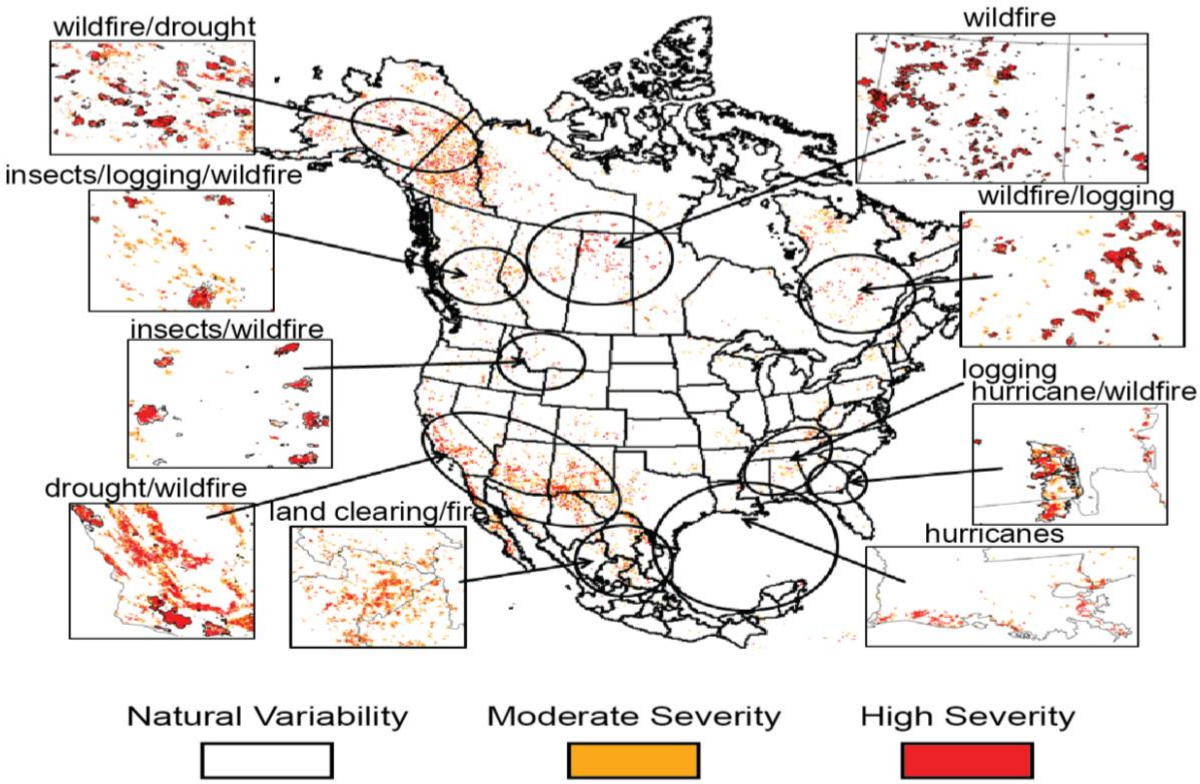

Figure 6. *An example of the variability and distribution of major ecosystem disturbance types in North America, compiled from 2005 to 2009. Forest disturbance varies by topography, vegetation, weather patterns, climate gradients, and proximity to human settlement. Severity is mapped as a percent change in a satellite-derived Disturbance Index. White areas represent natural annual variability, orange represents moderate severity, and red represents high*

severity. Fire dominates much of the western forest ecosystems, and storms affect the Gulf Coast. Insect damage is widespread but currently concentrated in western regions, and timber harvest is predominant in the Southeast. (Figure source: modified from Goetz et al. 2012) (NCA 2014).

a. Wildfire season is longer and impacts are more severe

Climate scientists have long known that increasing temperatures would increase drought conditions and the combination of drier and hotter weather would mean more frequent and severe wildfires. By 2006, scientists documented that the wildfire season in the western United States was 87 days longer than it was in the 1980s (Westerling et al. 2006). The number of large fires, >1000 acres, had grown four times, and the number of acres burned per year had increased six times. Recent studies have found the global wildfire season increased 19% globally from 1979–2013, and the global area vulnerable to wildfire increased 108% (Jolly et al. 2015). This will impact the many Plaintiffs in the West who suffer increased risk and severity of impacts from wildfires near their homes, in places that they visit for recreation, and in the air they breathe during the extended fire season, including Xiuhtezcatl, Jaime Lynn, Jacob, Sahara, Kelsey, Alex, Zealand, Nick, Aji, Nathan, Hazel and Avery. The lengthening of the fire season is largely due to declining mountain snowpack, earlier spring snowmelt, decreased summer precipitation and warmer summer temperatures. In the Pacific Northwest, the fire season length increased over the last four decades, from 23 days in the 1970s, to 116 days in the 2000s (Westerling 2016). Abatzoglou and Williams (2016) found that anthropogenic climate change from 1979–2015 added 55% to fuel aridity across western US forests. Dennison et al. (2014) found that from 1984–2011, the area of fire scars, or burned area, was increasing 355 km^2/year in the western United States (Figure 7).

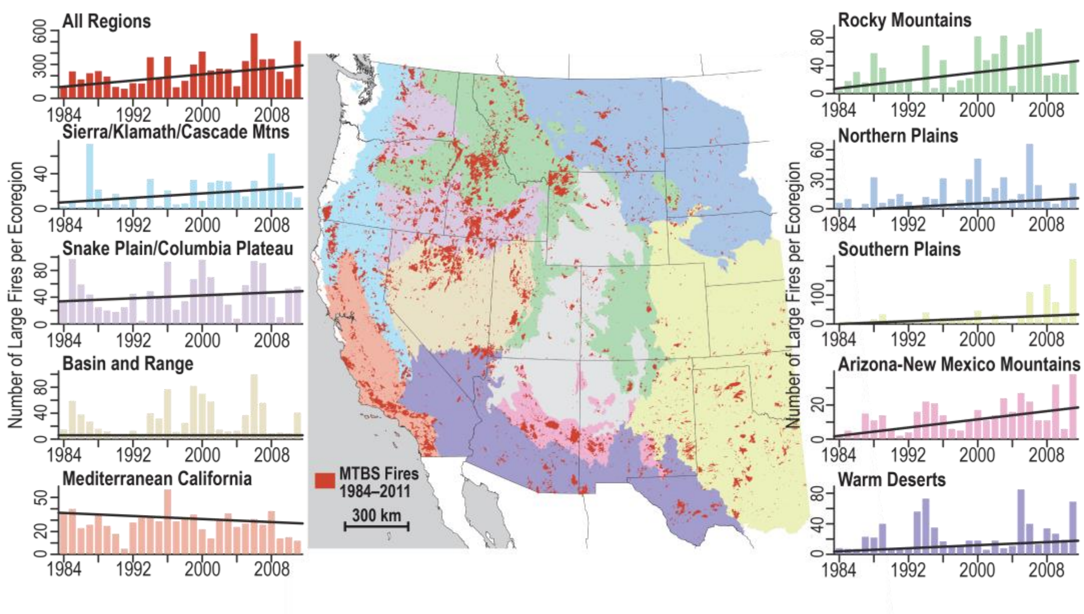

Figure 7. *Trends in the annual number of large fires in the western United States for a variety of ecoregions. The black lines are fitted trend lines. Statistically significant at a 10% level for all regions except the Snake Plain/Columbian Plateau, Basin and Range, and Mediterranean California regions. (Figure source: Dennison et al.2014) (USGCRP 2017).*

Holden et al. (2018) found that declines in summer rainfall had a major influence on western US wildfires over the past three decades. As reduced summer precipitation appears to exert strong control on wildfires through direct wetting effects (number of wetting days) and indirect feedbacks, future decreases in summer precipitation are predicted to increase wildfire activity.

b. Human health impacts

Wildfire smoke is having a deleterious effect aesthetically on atmospheric clarity and visibility in the western national parks, such as the parks visited by Plaintiff Xuihtezcatl for spiritual and recreational uses. In the late summer of 2017, wildfire smoke and ash also shrouded the city of Seattle, where Plaintiff Aji lives,[5] and much of Western Oregon, where Plaintiffs Avery, Hazel, Sahara, Zealand, and Jacob live. (Figures 8, 9).

Figure 8. *Photo of Plaintiffs Avery, Hazel, and Sahara in Eugene, OR on September 6, 2017 wearing masks to protect themselves from wildfire smoke*.

Additionally, acute health effects are documented from breathing smoky air in western cities, like the asthma attacks Plaintiff Sahara experiences. Smoke waves during 2004–2009 were associated with a 7.2% increase in respiratory hospital admissions among adults aged 65 and older in the western United States (Liu et al. 2016). Similarly, correlations were found between wildfire-specific PM2.5 and emergency department visits for asthma and chronic obstructive pulmonary disease during the 2012 wildfire season in Colorado (Alman et al. 2016) and the 2008 season in northern California (Reid et al. 2016). Across the western United States, PM2.5 levels

[5] Alan Blinder & Christina Caron, *Seattle Chokes as Wildfire Smoke from Canada Blankets the Northwest*, N.Y. TIMES, August 7, 2017, at https://www.nytimes.com/2017/08/07/us/wildfires-canada-seattle.html.

from wildfires are projected to increase 160% by mid-century under a medium emissions pathway (SRES A1B) (Yue et al. 2013, Liu et al. 2016). This translates to a greater risk of wildfire smoke exposure through increasing frequency, length, and intensity of "smoke waves"—that is, two or more consecutive days with high levels of PM2.5 from wildfires (Liu et al. 2016).

Figure 9. *Photo of Plaintiff Jacob on his farm outside Roseburg, OR on September 6, 2017 wearing a mask to protect himself from wildfire smoke.*

There is already evidence of accelerating forest mortality in western forests, and this acceleration is clearly tied to increasing temperatures and forest stress (Van Mentgem et al. 2009, Williams et al. 2013). The Forest Chapter of the National Climate Assessment in 2014 (NCA 2014), of which I was a Convening Lead Author, and the Northwest Regional chapter of the NCA 2014, identified accelerating disturbance rates as the single most detrimental impact for U.S. forests from climate change. For Plaintiffs Xiuhtezcatl, Jaime Lynn, Jacob, Sahara, Kelsey, Alex, Zealand, Nick, Aji, Nathan, Hazel and Avery, and other young people, their ability to recreate in many forests that they like to visit and that surround their homes is and will be harmed by the changes to these forests, including the increased levels of forest mortality that are occurring and are projected.

c. Loss of property

The Congressional Research Service has recognized that "wildfires can damage timber resources and soils and degrade water quality and watershed functions. Wildfires can also damage communities, destroy homes, and lead to loss of human life."[6] NOAA's National Centers for Environmental Information reports that in 2017, "66,131 fires (7th least since 2000) burned 9,781,062 acres (3rd most on record), which is 147.9 acres burned/fire (2nd most on record)."[7] For example, in late summer 2017, wildfires devastated many communities in Northern California, causing significant loss of property, including the mobile home park where Plaintiff Zealand's grandmother lived and where Zealand spent many winter holidays (Figure 10).

Figure 10. *Photo of Plaintiff Zealand's Grandmother's Mobile Home Park destroyed by wildfire in Northern California in 2017.*

The National Interagency Fire Center reported federal expenditures for wildfire fighting at $2.918 billion in 2017, the highest on record.[8] NOAA has tracked billion dollar plus weather and climate disasters in the U.S. for many years. According to NOAA's National Centers for Environmental Information:

> *During 2017, the U.S. experienced a historic year of weather and climate disasters. In total, the U.S. was impacted by 16 separate billion-dollar disaster events tying 2011 for the record number of billion-dollar disasters for an entire calendar year. In fact, 2017 arguably has more events than 2011 given that our analysis traditionally counts all U.S. billion-dollar wildfires, as regional-scale, seasonal events, not as multiple isolated events.*

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[6] Hoover, K., Congressional Research Service. 2017. Wildfire Management Funding: Background, Issues, and FY 2918 Appropriations, at https://fas.org/sgp/crs/misc/R45005.pdf.
[7] NOAA, NCDC. Wildfires – Annual 2017. https://www.ncdc.noaa.gov/sotc/fire/201713.
[8] National Interagency Fire Center. Federal Firefighting Costs (Suppression Only). https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf.

> *More notable than the high frequency of these events is the cumulative cost, which exceeds $300 billion in 2017 — a new U.S. annual record. The cumulative damage of these 16 U.S. events during 2017 is $306.2 billion, which shatters the previous U.S. annual record cost of $214.8 billion (CPI-adjusted), established in 2005 due to the impacts of Hurricanes Dennis, Katrina, Rita and Wilma.*[9]

NOAA specifically described the "Western Wildfires" and "California Firestorm" that occurred in 2017:

> *A historic firestorm damages or destroys over 15,000 homes, businesses and other structures across California in October. The combined destruction of the Tubbs, Atlas, Nuns and Redwood Valley wildfires represent the most costly wildfire event on record, also causing 44 deaths. Extreme wildfire conditions in early December also burned hundreds of homes in Los Angeles. Numerous other wildfires across many western and northwestern states burn over 9.8 million acres exceeding the 10-year annual average of 6.5 million acres. Montana in particular was affected by wildfires that burned in excess of 1 million acres. These wildfire conditions were enhanced by the preceding drought conditions in several states.*[10]

d. Bug epidemics (mountain pine beetle)

The largest forest insect epidemic in the world began in the forests of British Columbia in the mid-1990s. This mountain pine beetle epidemic has now moved as far south as New Mexico, and as of 2010 trees have been killed across 100 million acres of land (Raffa et al. 2008, Bentz et al. 2010), (Figures 11, 12), thereby impairing the ability of Plaintiffs Jaime Lynn and Xuihtezcatl to spend time in and enjoy the national forests they use. The trigger for this unprecedented epidemic is that milder winter temperatures have allowed beetle larvae to overwinter more successfully with less mortality. Previously, a midwinter extreme temperature of -40° F, occurring even only once per decade was sufficient to keep these populations low and not growing (Regniere and Bentz 2007). The longer, warmer summers now allow beetle larvae to complete more life cycles, allowing the population to multiply more quickly (Bentz et al. 2010). While the insect populations are faring better under climate change, the host trees are being stressed by the shorter winters and longer, hotter summers. This tree water stress, much like human dehydration, weakens the tree, and limits its ability to produce pitch and defensive chemicals to block the insect attacks (Hicke et al. 2012). The time-lapse series attached to my expert report as Exhibits F–G accurately depict trees being killed by pine beetles, and the short window of time in which it happens. These infestations can spread quickly through these forests, causing vast swaths of die off.

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[9] NOAA, National Centers for Environmental Information. Billion-Dollar Weather and Climate Disasters: Overview. https://www.ncdc.noaa.gov/billions/.

[10] NOAA, National Centers for Environmental Information. Billion-Dollar Weather and Climate Disasters: Table of Events. https://www.ncdc.noaa.gov/billions/events/US/1980-2017.

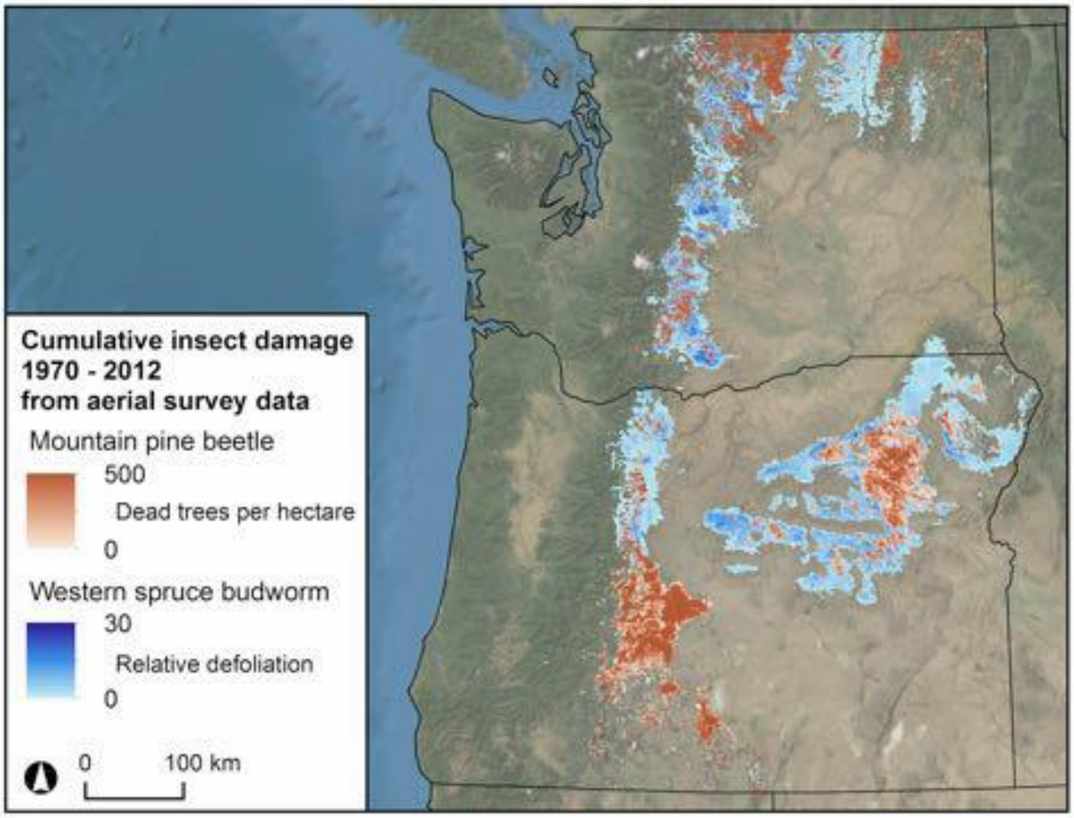


Figure 11. *Cumulative effects of western spruce budworm and mountain pine beetle on tree defoliation and mortality in forests of Oregon and Washington (1970–2012). Total forested area is about 25 million hectares, and these two insects affected 8 million hectares according to aerial surveys. Beetle overlaps budworm activity in this display. (Figure source: Garrett Meigs; data source: Meigs et al., 2015) (OCAR 2017).*

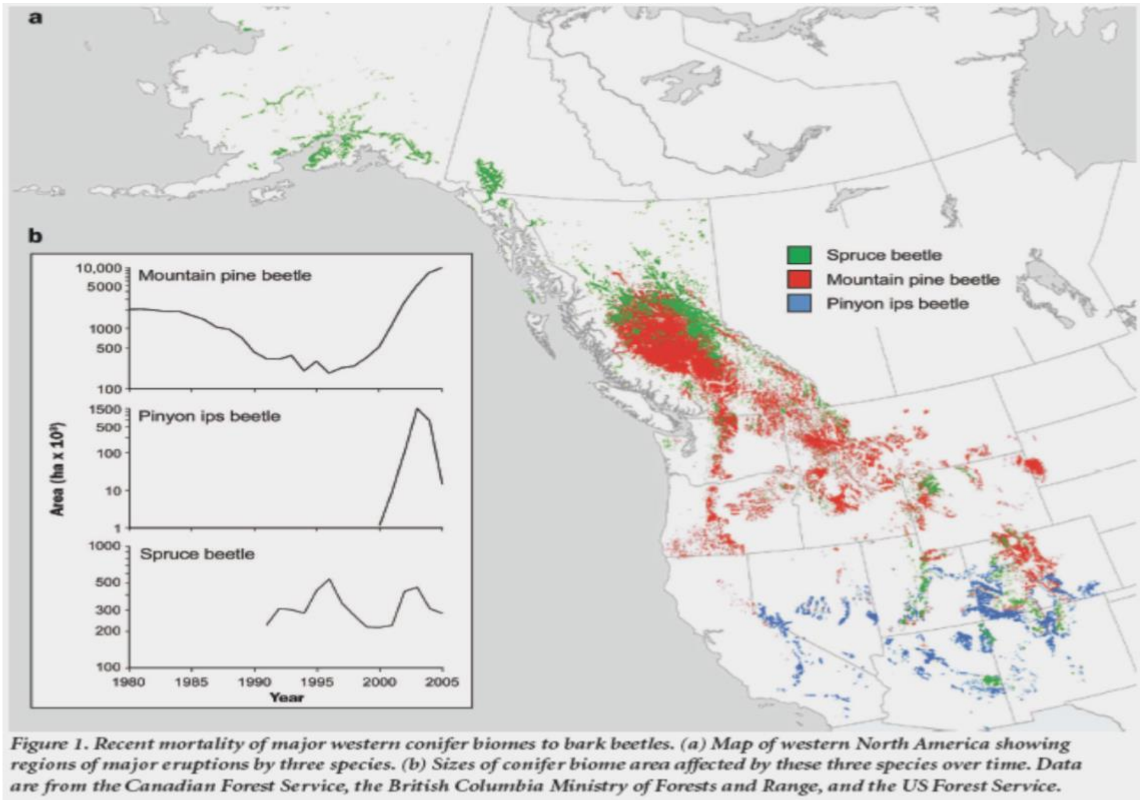
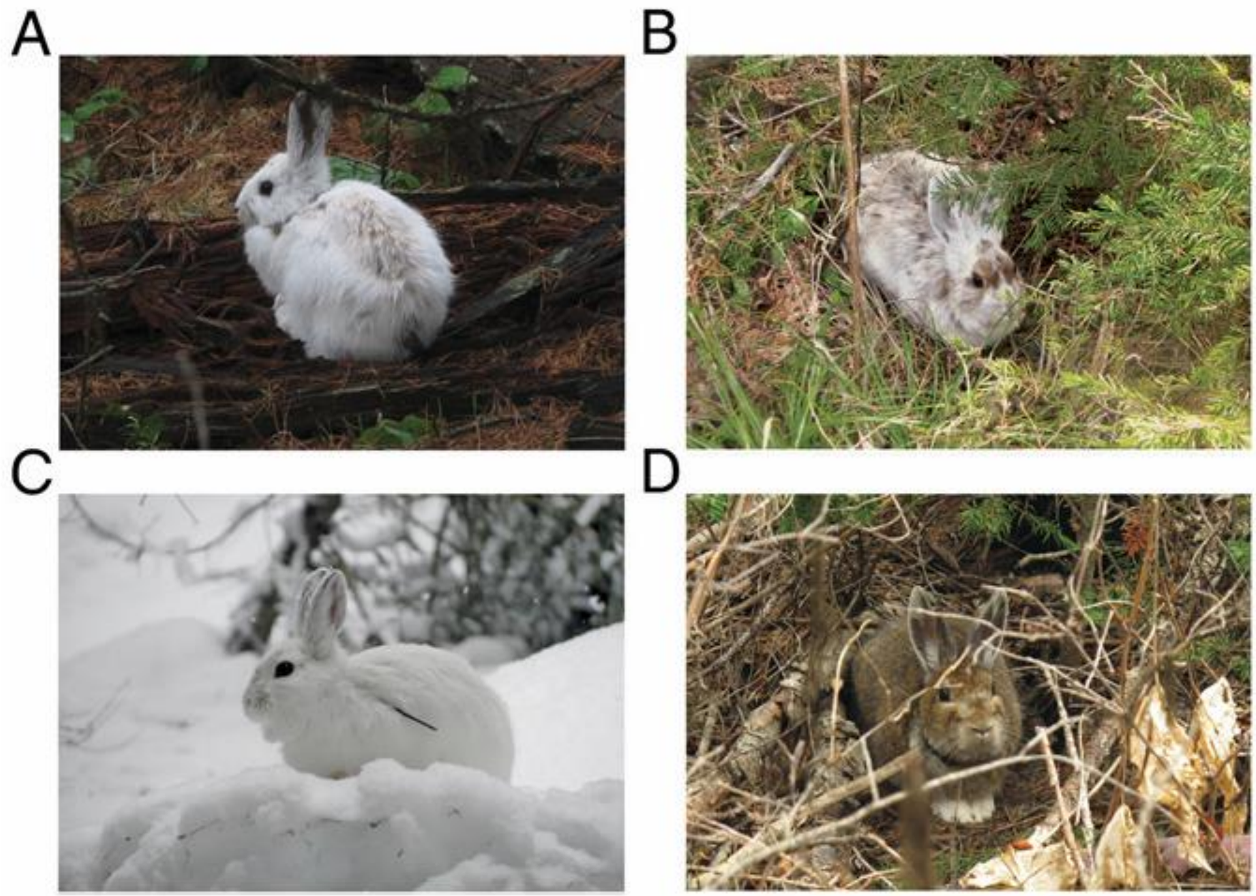


Figure 12. *Recent mortality of forests in major western biomes to three species of bark beetles. (Raffa et al. 2008, Bentz et al 2010).*

e. Impacts on wildlife: adaptation is not always possible.

Climate change is impacting wildlife on a wide scale now. A recent study (Ceballos et al. 2017) analyzed population data for 27,600 species worldwide. They found 32% have had significant population and geographic range declines. Of the 177 mammals in the study, all had lost at least 30% of their geographic range. The authors point out that even before total species extinction, significant declines in populations are occurring already. Much of this geographic range decline is because climate change is changing seasonal cycles, water and food availability, and stress tolerance limits of the animals.

While some species like coyotes are very adaptable, others have very tight ecological niches. Climate change affects wildlife in a variety of ways; some species will be more sensitive to climate change than others (Case et al. 2015). At-risk species generally have higher sensitivity scores than those species without Endangered Species Act designations (Case et al. 2015). Dependence on climate-sensitive habitats (such as seasonal streams, wetlands and vernal pools, seeps and springs, alpine and subalpine areas, grasslands and balds) is a large driver of species sensitivity (Case et al. 2015). The American pika is a relatively small mammal, and is active during the day but is intolerant of high temperatures. The pika is considered highly sensitive to climate change due in large part to its dependence on subalpine habitat and snow cover, which is also projected to decline (Case et al. 2016). In the Great Basin, American pika distribution has changed during the 2000s, primarily at the edges of its range, owing largely to decreases in maximum snowpack and growing season precipitation. As American pika shift to more climatically suitable habitat, they may be impeded by topographic relief, water features, and high heat exposure of west-facing slopes, as found in a study at Crater Lake (Castillo et al. 2014).



Types of contrast between seasonal coat color and snow background. Radiocollared snowshoe hares from this study showing (*A*) 100% contrast (mismatch), (*B*) 60% contrast (mismatch), (C) 0% contrast (no mismatch), and (*D*) 0% contrast (no mismatch).

Figure 13. *Illustration of the risk of mistimed seasonal coat color change in some animals. Climate change is increasing this risk to these animals (Mills et al. 2013, Mills et al. 2018).*

Shifts in annual timing of life history events are a common response of plant and animal populations to climate change (Mills et al. 2013, Mills et al. 2018). In many cases, these phenological shifts span multiple trophic levels, creating mistiming as animal reproduction, hibernation emergence, or migration become detached from peak timing of food or habitat structure. A much more direct phenological mismatch could occur for the mammal species that molt seasonally from brown to white so that coat color tracks the presence of snow, known as cryptic coloration (Figure 13). A decrease in the number of days with seasonal snow on the ground is one of the temperate region's strongest climate change indicators. Mills et al. (2013), studying snowshoe hares in Montana, used downscaled CMIP5 GCM projections to evaluate potential for the seasonal color change of these hares to become mismatched with seasonal snowfall. Mills et al. found that seasonal snowpack duration in this region is expected to decrease 29–35 days by mid-century, and 40–69 days by 2100. More critically, this snowpack change is four times faster at midcentury and eight times faster by late century than the observed phenotypic plasticity of these hares. As the pictures illustrate, this timing mismatch makes these hares highly vulnerable to their local natural predators.

PART B: INTERPRETING PROJECTIONS

1. Future Projections of climate and ecosystem impacts for the western United States

Klos et al. (2014) project that by mid-century with a BAU emissions pathway (RCP 8.5) that 53–34% of the western United States that receives snowfall currently will be lost, changed to winter rainfall, and that the time of annual snowcover in the West will drop from 5 months to 3 months. A similar study by Naz et al. (2016) projects overall 25 days of less snowcover by mid-century in the West. Boisvenue and Running (2010) projected that spring snowmelt at West Glacier, Montana which began on April 8th in 1950, will begin on February 25th by 2089.

By 2050, the snow water equivalent (SWE) in snowpack in the Pacific Northwest will decline 30 percent more and by 2100 by 50 percent (OCAR 2017). Future streamflow magnitude and timing in the Pacific Northwest is projected to shift toward higher winter runoff, lower summer and fall runoff (Figures 14 and 15), and an earlier peak runoff, particularly in snow-dominated regions (Naz et al. 2016).

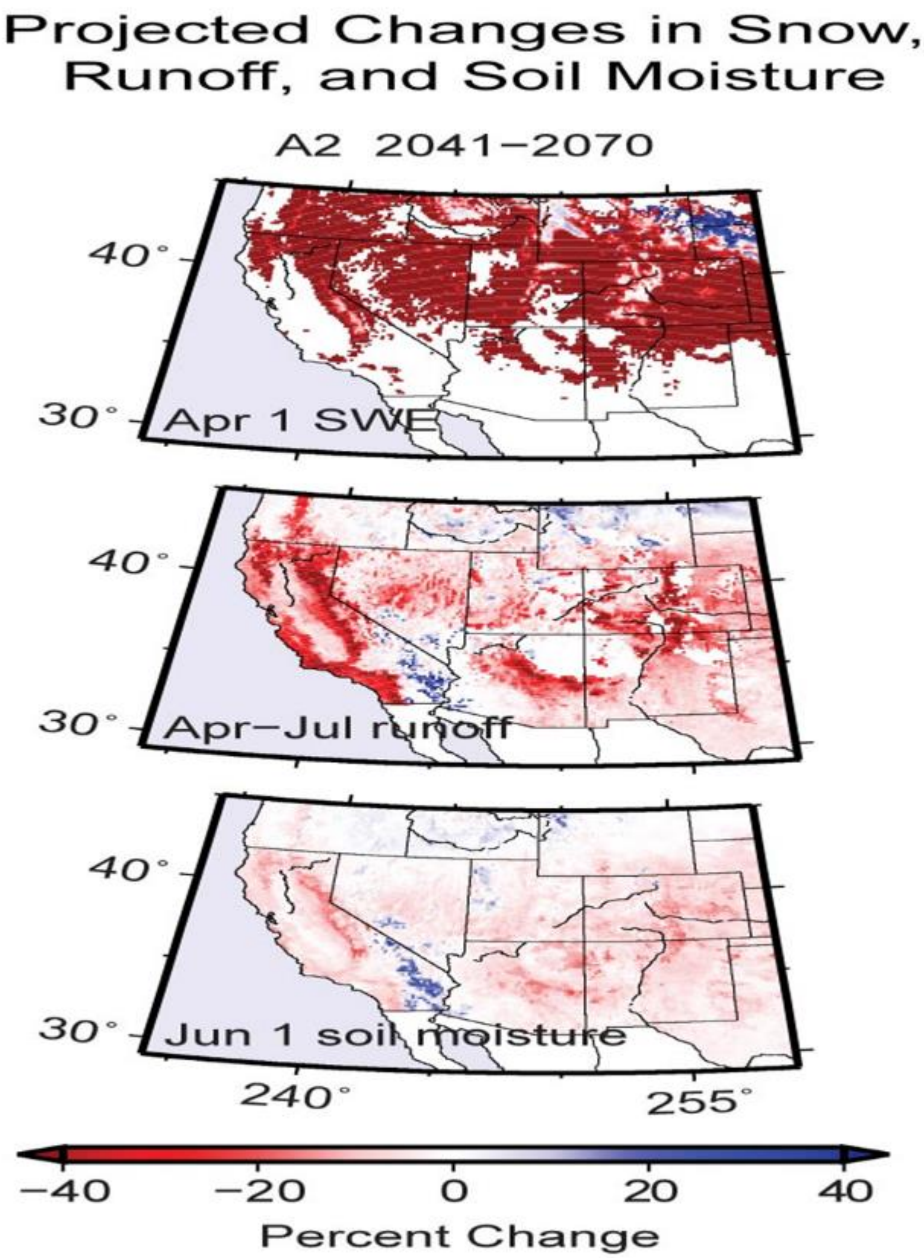


Figure 14. *These projections, assuming continued increases in heat-trapping gas emissions (A2 scenario = RCP 8.5), illustrate: a) major losses in the water content of the snowpack that fills western rivers (snow water equivalent, or SWE); b) significant reductions in runoff in California, Arizona, and the central Rocky Mountains; and c) reductions in soil moisture across the Southwest. The changes shown are for mid-century (2041–2070) as percentage changes from 1971–2000 conditions (Cayan et al. 2013, NCA 2014).*

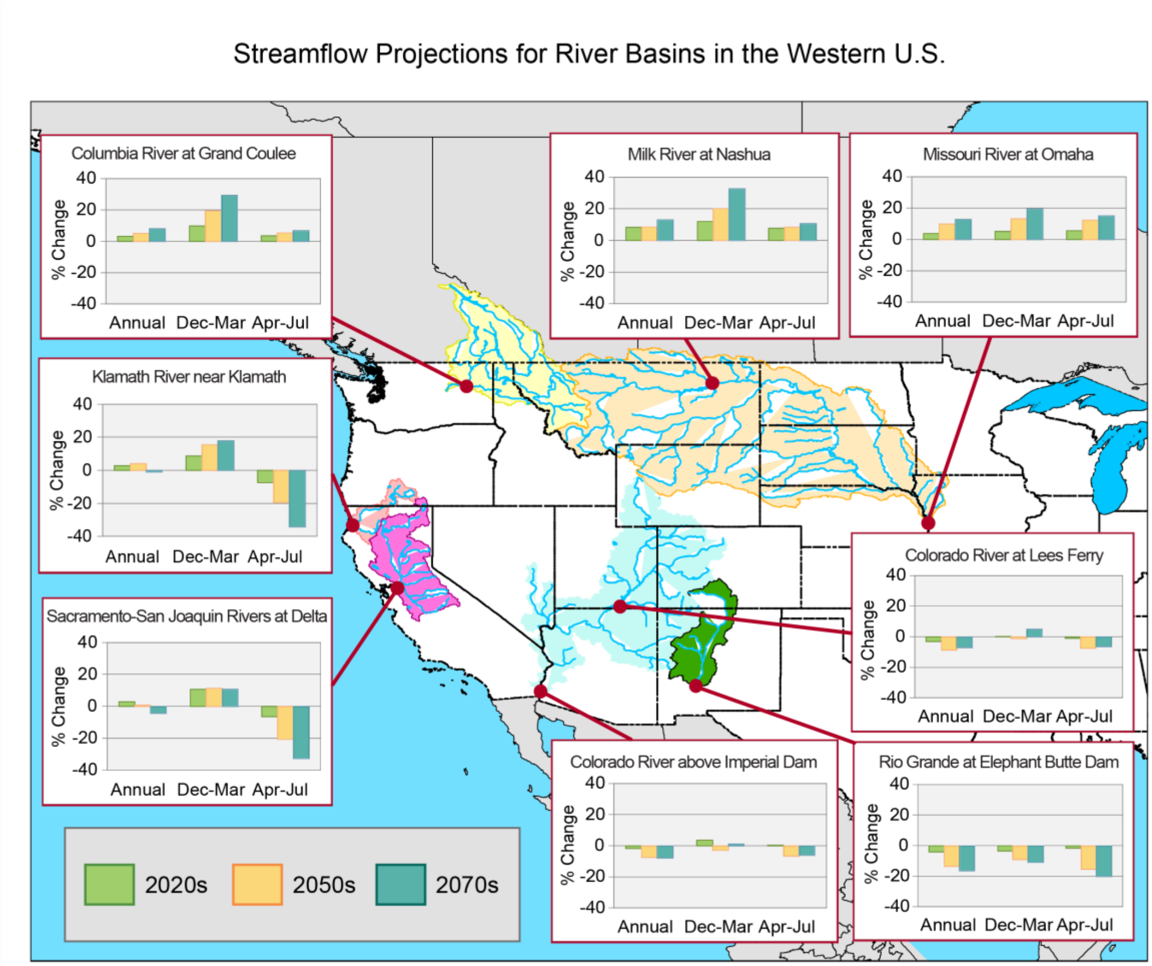


Figure 15. *Annual and seasonal streamflow projections based on the B1 (with substantial emissions reductions), A1B (with gradual reductions from current emission trends beginning around mid-century), and A2 (with continuation of current rising emissions trends) CMIP3 scenarios for eight river basins in the western United States. The panels show percentage changes in average runoff, with projected increases above the zero line and decreases below. Projections are for annual, cool, and warm seasons, for three future decades (2020s, 2050s, and 2070s) relative to the 1990s. (Source: U.S. Department of the Interior – Bureau of Reclamation 2011; Data provided by L. Brekke, S. Gangopadhyay, and T. Pruitt (NCA2014).*

a. Severe moisture/floods/snowmelt at extremes

Warming temperatures and increased winter precipitation are expected to increase flood risk for many basins in the Pacific Northwest, particularly mixed rain-snow basins with near freezing winter temperatures (Tohver et al. 2014). Salathe et al. (2014) calculated that the risk of 100 year floods in the Pacific Northwest could double by mid-century as a result of heavier fall rains, and winter rain on snow events.

The University of Washington Climate Impacts Group predicts increased flooding in most watersheds in Washington state:

> *Projected changes in streamflow volume associated with the 100 year (1% annual probability) flood event, by basin type, in Washington State for the 2080s (2070-2099, relative to 1916-2006:*
>
> > *Rain dominant watersheds: +18% (range: +11 to +26%)*
> > *Mixed rain-snow watersheds: +32% (range: -32 to +132%)*
> > *Snow dominant watersheds: -2% (range: -15 to 22%)*
>
> *Projected changes in heavy rainfall . . . are not included in the above projections. Preliminary research indicates an increase in the proportion of heavy rain events occurring in early fall. Both changes will likely increase flood risk in rain dominant and mixed rain and snow watersheds, especially west of the Cascade crest.*[11]

b. Severe droughts

In the Pacific Northwest, the median summer drought extent across multiple climate models is less than 15% in the historical period, but jumps to over 50% during the 21st century. Changes are for 2011–2050 under the high (RCP 8.5) emissions pathway relative to 1966–2005 (Naz et al. 2016). Naz et al. also project April 1 snow water equivalent to decline 20% during this period. (Naz et al. 2016). The largest droughts, which cover nearly half of the region in the historical period, cover nearly the entire region in future projections (Ahmadalipour et al. 2016).

Cayan et al. (2010) analyzed the historical frequency of major droughts in the desert Southwest, finding that five droughts between 4–10 years of duration have occurred since 1950. Their future hydrologic model projections for the Southwest using a downscaled ensemble of 12 GCMs, and A2 emission scenario from the IPCC 4th Assessment project that there will be 9–13 major droughts between 2050–2099. These projections mean that in the future, drought episodes will be more common than "normal" climate, so that in fact normal is shifting to a permanently more arid Southwest, with severe consequences for all human freshwater consumption in the region.

2. Future impacts to terrestrial ecosystems with continued BAU emissions

As global emissions continue to rise, all global climate models project higher global temperatures in the coming decades. With current national policies, temperatures in the Pacific Northwest could rise 10 degrees Fahrenheit (°F). A 10°F increase in temperatures would result in extreme and irreversible harm to terrestrial ecosystems, leading to more extreme weather events, species extinctions, and sea level rise inundating major coastal cities worldwide. The resulting

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[11] Snover, A.K., G.S. Mauger, L.C. Whitely Binder, M. Krosby, and I. Tohver. 2013. *Climate Change Impacts and Adaptation in Washington State: Technical Summaries for Decision Makers.* State of Knowledge Report prepared for the Washington State Department of Ecology. Climate Impacts Group, University of Washington, Seattle at 6-11.

harms to human society will also be substantial and would include disruption of agricultural production, famine, disease and climate refugees fleeing uninhabitable countries generating ongoing immigration crises. Tropical diseases and invasive pests are already moving north into the Pacific Northwest and this trend will accelerate. A 10°F temperature increase by the end of this century will virtually eliminate the winter snowpack and will at least quadruple our wildfires. Figure 16 illustrates that spring and summer soil moisture will decline across the western U.S. as higher evaporation rates consume the antecedent rainfall.

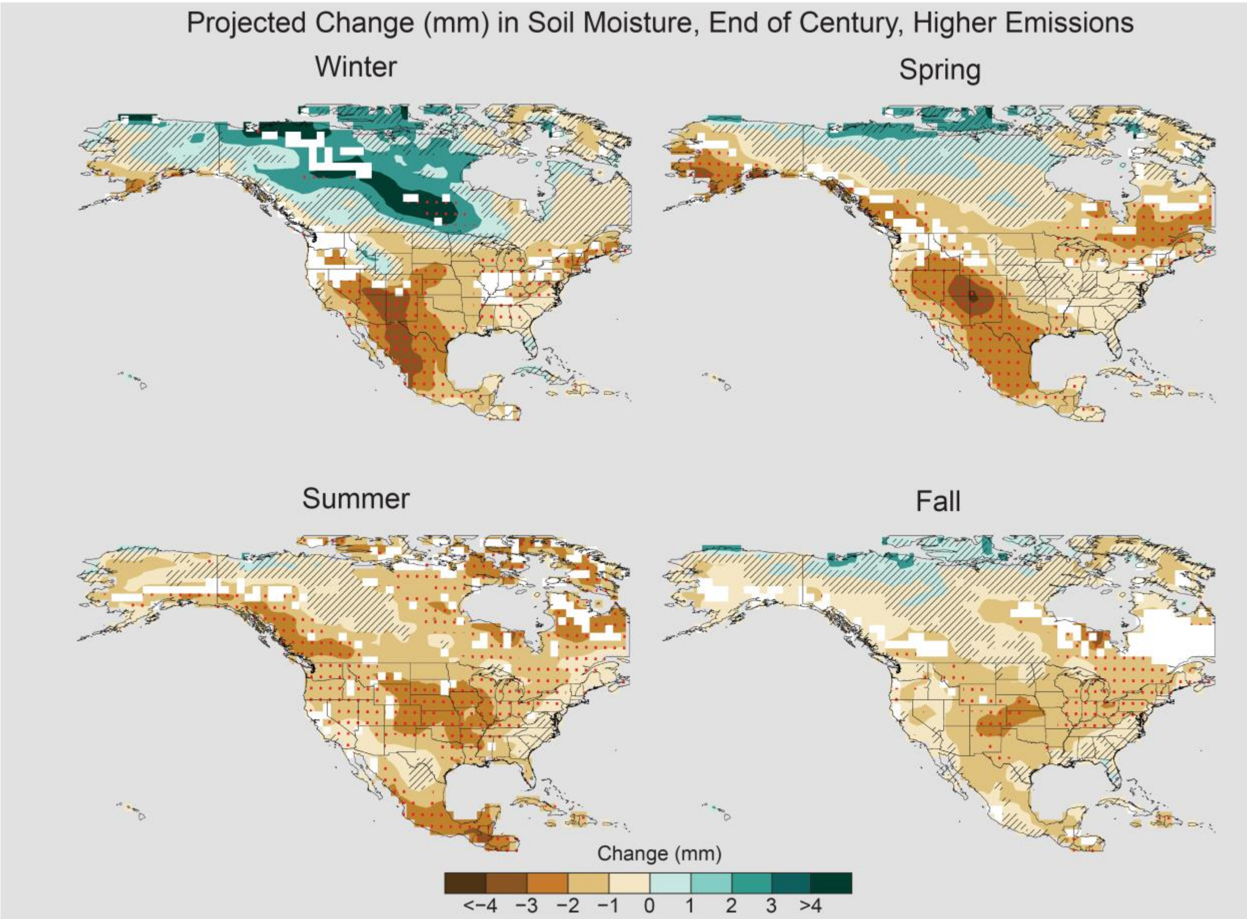

Figure 16. *Projected end of the 21st century weighted CMIP5 multimodel average percent changes in near surface seasonal soil moisture under the higher scenario (RCP 8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hashing indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive (Figure source: NOAA NCEI and CICS-NC). (USGCRP 2017).*

a. Vulnerabilities and projections for terrestrial ecosystems under changing climatic conditions.

Vegetation can adapt to changing local environmental conditions in a variety of ways (OCAR 2017). First, individual trees have inherent survival mechanisms that enable them to respond and adapt to changing conditions. However, this ability to acclimate in place is limited even for the most tolerant species. Secondly, tree species can adapt by genetically evolving through natural selection. This type of evolution takes several generations, reducing the potential for rapid population acclimation but a latitudinal or elevational gradient within the species range may provide the genetic diversity needed to manage future forests. Lastly, tree species can adapt to a changing climate by migrating to areas with more suitable climate conditions. These three mechanisms provide pathways for adaptation; however, the rate of climate induced shifts in habitat are expected to outpace the reorganization of forest stand structure and species composition through evolution and migration (Figure 17). Subalpine forests are most at risk, as suitable habitat for these species is projected to be severely reduced or even non-existent by the end of the 21st century (Vose et al. 2016).

Stand replacing fires open up the canopy and facilitate vegetation shift. With climate change, the tree species that grow back after a fire may be different from those that previously existed (Sheehan et al. 2015). This vulnerability may result in the loss of these high-elevation habitats, affecting associated wildlife and biodiversity (Littell et al. 2013). High-elevation energy-limited forests may experience increased tree growth under future warmer conditions and elevated atmospheric CO_2 concentrations. Dynamic global vegetation models consistently project the contraction of sub-alpine forests and the expansion of temperate forests (Littell et al. 2013, Sheehan et al. 2015). However current analyses show that climate and species habitat requirements are changing faster than species can adapt, or move either in elevation or in latitude (Dobrowski et al. 2016). These species maladapted to the new, and rapidly changing conditions will die out.

Forest Vulnerability to Changing Climate

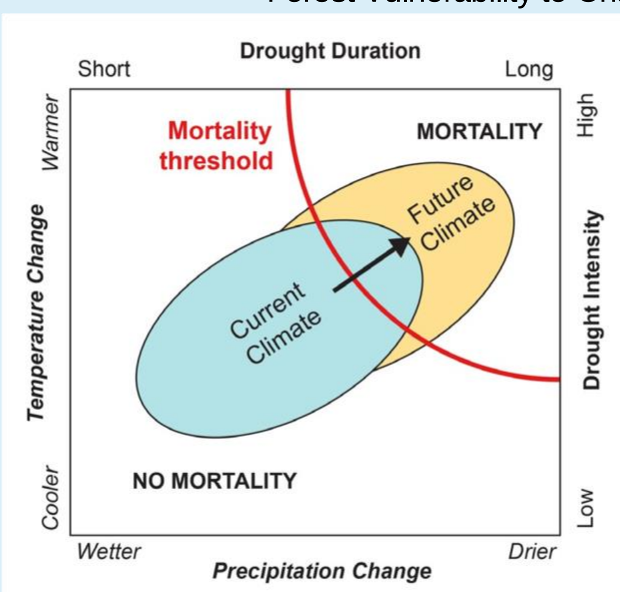

Figure 7.3. The figure shows a conceptual climate envelope analysis of forest vulnerability under current and projected future ranges of variability in climate parameters (temperature and precipitation, or alternatively drought duration and intensity). Climate models project increasing temperatures across the U.S. in coming decades, but a range of increasing or decreasing precipitation depending on region. Episodic droughts (where evaporation far exceeds precipitation) are also expected to increase in duration and/or intensity (see Ch. 2: Our Changing Climate). The overall result will be increased vulnerability of forests to periodic widespread regional mortality events resulting from trees exceeding their physiological stress thresholds.[11] (Figure source: Allen et al. 2010[11]).

Figure 17. *Conceptual figure showing how temperature and precipitation changes are moving our forests into conditions of higher mortality (NCA 2014).*

The natural and higher elevation forests of the Pacific Northwest are already showing acceleration of insect epidemics, forest disease and wildfire. Future projections suggest both of these disturbance dynamics will increase even further as climate change progresses (Figure 18). Currently snow dominated subalpine forests may transition to other forest types as a result of declining snowpack, increased summer forest stress and disturbance rates.

Insects and Fire in Northwest Forests

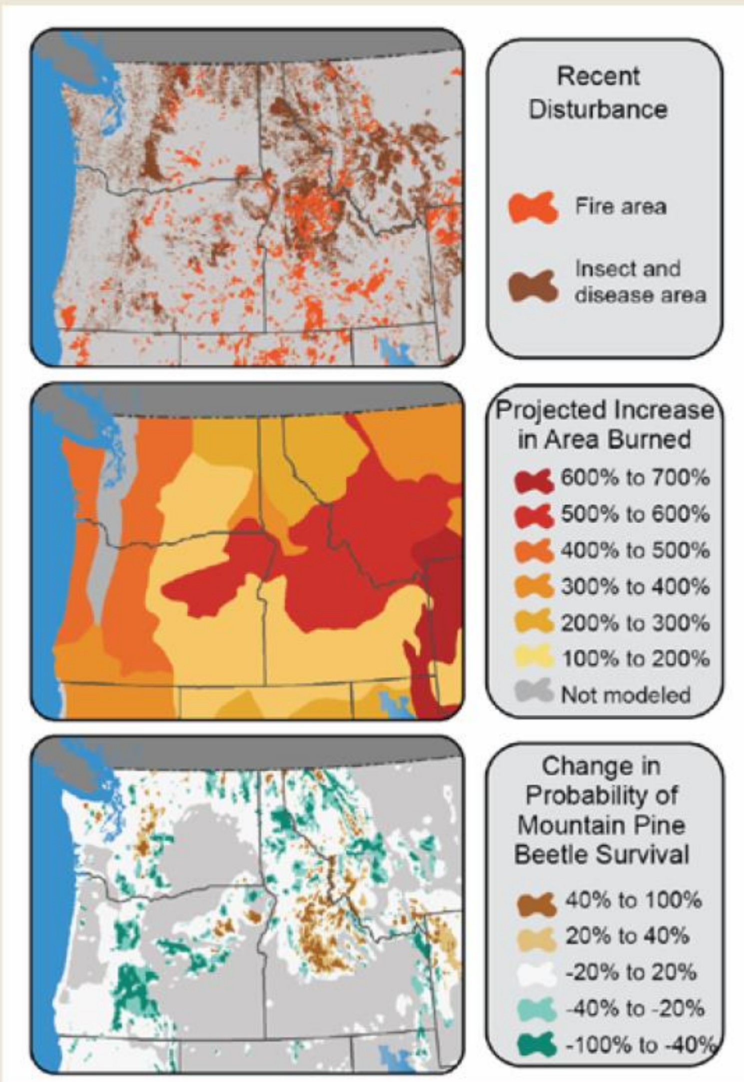

Figure 21.7.

(Top) Insects and fire have cumulatively affected large areas of the Northwest and are projected to be the dominant drivers of forest change in the near future. Map shows areas recently burned (1984 to 2008)[97,98] or affected by insects or disease (1997 to 2008).[99]

(Middle) Map indicates the increases in area burned that would result from the regional temperature and precipitation changes associated with a 2.2°F global warming[100] across areas that share broad climatic and vegetation characteristics.[101] Local impacts will vary greatly within these broad areas with sensitivity of fuels to climate.[14]

(Bottom) Projected changes in the probability of climatic suitability for mountain pine beetles for the period 2001 to 2030 (relative to 1961 to 1990), where brown indicates areas where pine beetles are projected to increase in the future and green indicates areas where pine beetles are expected to decrease in the future. Changes in probability of survival are based on climate-dependent factors important in beetle population success, including cold tolerance,[102] spring precipitation,[103] and seasonal heat accumulation.[91,92]

Figure 18. *Projections of future insect and wildfire disturbance dynamics for the Pacific Northwest (NCA 2014).*

b. Climate Change is already significantly harming federal public lands

Federal public lands are already being impacted by climate change, including from the aforementioned drought conditions, wildfires, insect outbreaks, harm to species, and from volatile weather patterns. As documented in Figure 18, future wildfire activity may be 200–600% higher than today in the Pacific Northwest. Our conclusion in the Forests chapter of the 2014 National Climate Assessment is that accelerating disturbance and mortality are the single greatest threats to US forests, and negative impacts are already occurring. A similar climate change projection for the entire western United States shows that even a 1°C increase in global temperatures may result in increased wildfire activity throughout the West (Figure 19).

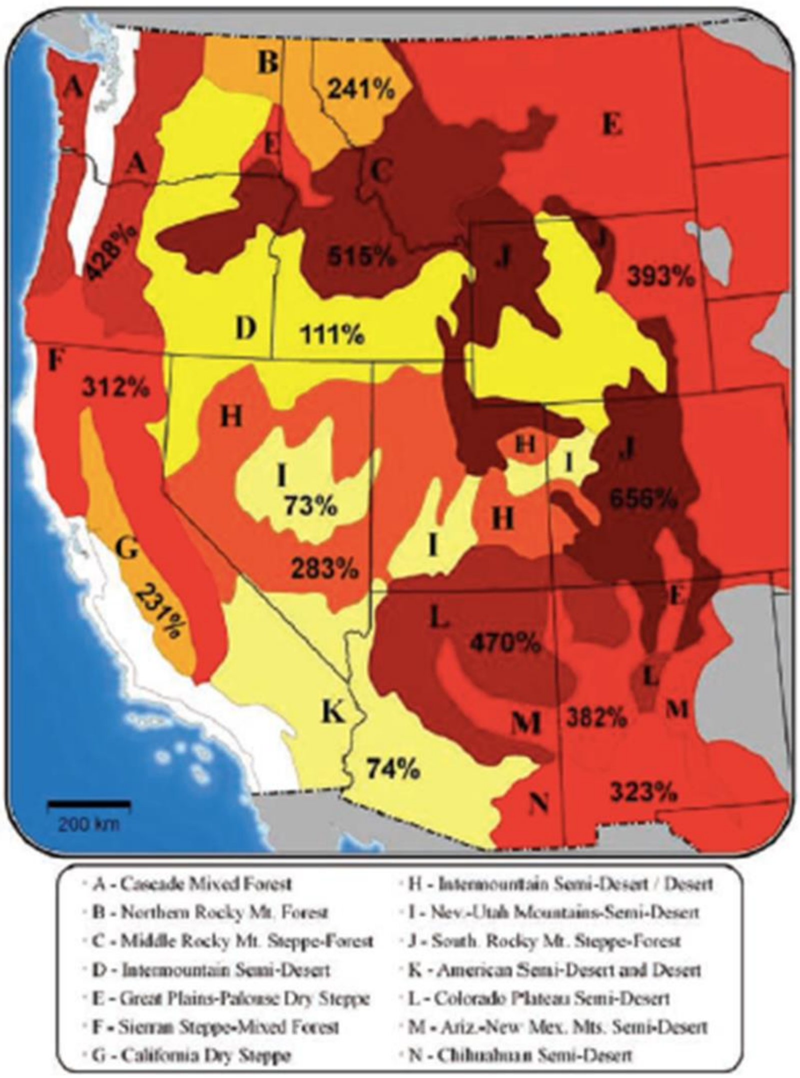

Figure 19. *Projected wildfire increases in the western U.S.: "Percent increase (relative to 1950–2003) in median annual area burned for ecoprovinces of the West with a 1ºC increase in global average temperature." (Source: National Research Council 2011).*

According to Defendant U.S. Department of Agriculture, sixty million Americans obtain their drinking water from sources that originate on 193 million acres of national forest and grasslands and those sources are under threat from drought conditions in many places (Vose et al. 2016). According to Defendant U.S. Department of the Interior, it "manages one-fifth of the land in the

United States, 35,000 miles of coastline, and 1.7 billion acres of the Outer Continental Shelf."[12] Ecosystem disturbance rates of the magnitude shown in Figures 18 and 19 will very likely degrade drinking water sources in many areas of the West.

3. Protection of terrestrial ecosystems in the U.S. require urgent and rapid reductions of GHG emissions.

If humanity reduces carbon emissions significantly in the near-term, the increase in global temperatures could be kept to 1.5°C in the short-term, stabilizing at 1°C by the end of the century (Hansen et al. 2013). Any additional increase in global temperatures will cause substantial changes to global terrestrial ecosystems. I, and other scientists, are concerned that there may be some poorly understood tipping points, such as melting of the Greenland ice-sheet increasing sea level that, once passed, make the melt-out unstoppable. However, most system responses are thought to be proportional. Thus reducing carbon emissions reduces CO_2 in the atmosphere proportionally, which reduces temperature increases and impacts proportionally. It is not too late to take action to slow and eventually halt climate change. In my expert opinion it is critical that action to reduce carbon emissions and increase carbon sequestration occur immediately. The federal government has for 40 years had knowledge, information, and scientific recommendations that it needed to transition the nation off of fossil fuels in order to first prevent against, and now try to stop, catastrophic climate change. We are well beyond the maxim: "If you find yourself in a hole, quit digging."

CONCLUSION

Atmospheric concentrations of carbon dioxide and other greenhouse gases (GHG) have been increasing at substantial rates as a consequence of human combustion of fossil fuels. This increase in GHG concentrations is causing global temperatures to increase, resulting in reduction in the extent of polar sea ice, glacial mass, and of regional concern, seasonal snowpack. This in turn is causing reduced summer flows in rivers, increased wildfires and insect epidemics in forests. These adverse ecological impacts are also harming wildlife. These impacts are evident both globally and in the western United States region. Global and national temperatures will continue to increase as a result of failure to control carbon emissions.

The United States Government has known in massive detail the science of global warming for at least 40 years. Should greenhouse gas emissions in the United States continue on a business as usual (BAU) course, the impacts described in this report will worsen and the means of preventing the worst of the impacts we project throughout the century will be limited. Future projections of increasing atmospheric CO_2 will continue the geographic expanse and severity of these negative impact trends for the foreseeable future. The inaction of our government over this time to reduce emissions as needed to stabilize the climate system (Hansen et al. 2013) will serve to penalize future generations of Americans, including the Plaintiffs, for as far into the future as I can imagine. The only solution is swift decarbonization of our energy system and urgent efforts to protect the terrestrial biosphere so that it can sequester more carbon.

[12] U.S. Department of the Interior. Climate Change. https://www.doi.gov/climate.

Signed this 12th day of September, 2018 in Missoula, Montana.

EXHIBIT A: CV

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Education:

Ph.D.	Forest Ecophysiology; Colorado State University, Fort Collins, 1979
M.S.	Forest Management; Oregon State University, Corvallis, 1973
B.S.	Botany; Oregon State University, Corvallis, 1972

Experience:

2017 -	Regents Professor Emeritus
2007-2017	Regents Professor, University of Montana
2008	Visiting Professor, Universitat de Bodenkultur, Vienna, Austria
1988-2007	Professor, Forest Ecology, College of Forestry & Conservation, University of Montana
2005	Visiting Professor, University of Firenze, Florence, Italy
2003	Professor, Visiting McMaster Fellow, CSIRO Land and Water, Canberra, ACT Australia
1993	Visiting Sabbatical Scientist, Dept of Plant Ecology, Lund University, Sweden
1986-87	Visiting Sabbatical Scientist, CSIRO Division of Forest Research, Canberra, Australia
1983-1988	Associate Professor, Forest Ecophysiology, School of Forestry, University of Montana
1979-1983	Assistant Professor, Forest Ecophysiology, School of Forestry, University of Montana
1979	Senior Research Associate, Natural Resource Ecology Laboratory, Colorado State University
1976-1979	Research Forester, Forest and Mtn Meteorology Project, Rocky Mtn Forest and Range Experiment Station, Fort Collins, Colorado
1976-1979	Graduate Research Assistant, Dept. of Forest and Wood Sciences, Colorado State University
1974-1976	Research Assistant, Coniferous Forest Biome, Oregon State University
1973-1974	Forest Ecologist, Environmental Associates Inc., Corvallis, Oregon

Society Affiliations:

American Geophysical Union
American Meteorological Society
Ecological Society of America

Awards, Honors:

Personal Audience Her Royal Highness Princess Maha Chakri Sirindhorn, Bangkok, Thailand
NASA-USGS 2015 William T. Pecora Award
ISI World's Most Influential Minds, Geosciences 2014, 2015, 2017
Montana Environmental Information Center Conservationist of the Year 2012
Doctor Honoris Causa University of Natural Resources and Life Sciences, Vienna Austria 2012
Honorary Professor, Environment Institute and Dept. of Geography, University College London 2009
Oregon State University Distinguished Alumni Fellow 2009
E. O. Wilson Biodiversity Technology Pioneer Award 2009
Chapter lead author of IPCC 2007 report, awarded the Nobel Peace Prize 2007
Univ. Of Montana Presidential Scholar 2008
University of Montana, Lud Browman Award for scientific writing, 2007
Oregon State Univ. College of Forestry, Distinguished Alumni, 2006
Burk-Brandenburg Montana Conservation Award, 2006

ISI Highly Cited Scientist Designation 2004-2013
Fellow of the American Geophysical Union, 2002
University of Montana BN Faculty Achievement Award, 1991
University of Montana, Distinguished Scholar, 1990

Nat'l/Int'l Committee Appointments:

NASA Science Committee 2013 - 2017
NASA Earth Science Subcommittee 2009 – 2015, Chair 2013- 2017
NOAA Climate Working Group, 2009 - 2014
National Academy of Sciences, NRC Committee on Ecological Impacts of Climate Change, 2008.
NCAR CCSM Land Model Working Group (LMWG) Co-Chair, 2006-2008.
AGU Committee of Fellows 2006-2008.
Dept of Energy, Terrestrial Carbon Science Research Program, Co-Chair, 2005-2006.
National Research Council, NASA Earth Science Decadal Survey, 2005-2006.
NRC Committee on Environmental Satellite Data Utilization 2002-2005.
Intergovernmental Panel on Climate Change, Chapter Lead Author 2004-2007.
International Geosphere-Biosphere Programme Science Executive Committee 2004-2007.
National Research Council: Committee on Earth Studies 2004-2006.
NCAR CCSM Land Model Working Group (LMWG) Co-Chair, 2002-2004.
Interagency Carbon Cycle Science Committee 2002 – 2005.
NAS-NRC Review of NASA Earth Science Enterprise Science Plan for 2000-2010.
NASA - Earth Observing System MODIS Science Team Member, 1989-2007.
NCAR Climate System Model (CSM) Advisory Board, 1996-2000.
NASA Mission to Planet Earth Biennial Review Panel, 1997.
Terrestrial Observation Panel for Climate of the World Meteorological Organization, 1995-2001.
National Academy of Sciences, NRC, Climate Research Committee, 1995-2001.
NRC Panel on Climate Observing System Status, 1998.
NSF - National Center for Ecological Analysis and Synthesis, Science Advisor Board, 1994-1997.
NASA Earth Observing System, Land Science Panel, Chair 1994-2000.
World Climate Research Program, International Land Surface Climatology Science Panel, 1994-1996.
World Climate Research Program, Global Terrestrial Observing System Committee, 1994-1995.
International Geosphere-Biosphere Program, Biospheric Aspects of the Hydrologic Cycle, Vice-Chair, 1991-1996.
National Science Foundation, Ecosystem Studies Program panel member 1991-1993.
World Climate Research Program - WCRP/IGBP Land Surface Experiments, 1990-1994.
NASA Earth Science and Applications Advisory Subcommittee, 1990-1993.
NASA Boreal Forest Ecosystem-Atmosphere Study (BOREAS) Steering Committee, 1989-1991.
International Geosphere-Biosphere Program - Committee on Global Hydrology, 1988-1990.
NASA - Terrestrial Ecosystems Program Advisory Group, 1988-1990.
NASA - Management Operations Working Group, 1988-1990.
NASA - Interdisciplinary Studies Review Panel, 1986.
NASA - MODIS Instrument Panel, 1984-1986.
NASA - Global Biology Review Panel, 1983-1984.
National Academy of Sciences, Space Science Board participant, 1982-1984.
NASA - Land Related Global Habitability Program Planning, 1982-1983.

Proposal Reviewer:

American Institute of Biological Sciences
California Space Institute
Canada Foundation for Innovation
National Aeronautics and Space Administration
National Oceanic and Atmospheric Administration
National Environmental Research Council of the United Kingdom
National Science Foundation
Natural Sciences and Engineering Research Council of Canada
U.S. Dept. of Energy
U.S. Environmental Protection Agency
U.S. Geological Survey
U.S.D.A. Cooperative Research Program
Western Regional Center of the National Institute for Global Environmental change

Journal Referee:

Agricultural and Forest Meteorology
Agronomy Journal
AI Applications in Natural Resource Management
American Naturalist
Australian Journal of Forest Research
Bioscience
Canadian Journal of Botany
Canadian Journal of Forest Research
Canadian Journal of Remote Sensing
Climatic Change
Climate Research
Ecological Applications
Ecology
Forest Science
Global Change Biology
Int'l Journal of Hydrological Processes
Int'l Journal of Remote Sensing
Journal of Applied Meteorology
Journal of Climate
Journal of Environmental Quality
Journal of Geophysical Research
Journal of Hydrology
Journal of Range Management
National Geographic Research and Exploration
Nature
Northwest Science
Remote Sensing of Environment
Science
Tellus
The National Academies
Tree Physiology
USFS Intermountain Forest and Range Experiment Station
USFS Pacific Northwest Forest and Range Experiment Station
USFS Rocky Mountain Forest and Range Experiment Station
Water, Air and Soil Pollution
Water Resources Research

EXHIBIT B: LIST OF PUBLICATIONS (LAST TEN YEARS)

Jones, M.O., S.W. Running, J.S. Kimball, N.P. Robinson, and B.W. Allred. (2018). Terrestrial primary productivity indicators for inclusion in the National Climate Indicators System. Climatic Change https://doi.org/10.1007/s10584-018-2155-9.

Kimball, H. L., Selmants, P. C., Moreno, A., Running, S. W., & Giardina, C. P. (2017). Evaluating the role of land cover and climate uncertainties in computing gross primary production in Hawaiian Island ecosystems. PloS one, 12(9), e0184466.

Robinson, N. P., Allred, B. W., Jones, M. O., Moreno, A., Kimball, J. S., Naugle, D. E., Running,S. & Richardson, A. D. (2017). A Dynamic Landsat Derived Normalized Difference Vegetation Index (NDVI) Product for the Conterminous United States. Remote Sensing, 9(8), 863.

Hasenauer, H., Neumann, M., Moreno, A., & Running, S. (2017). Assessing the resources and mitigation potential of European forests. Energy Procedia, 125, 372-378.

Madani, N., Kimball, J. S., & Running, S. W. (2017). Improving Global Gross Primary Productivity Estimates by Computing Optimum Light Use Efficiencies Using Flux Tower Data. Journal of Geophysical Research: Biogeosciences, 122(11), 2939-2951.

Mildrexler, D. J., Zhao, M., Cohen, W. B., Running, S. W., Song, X. P., & Jones, M. O. (2017). Thermal anomalies detect critical global land surface changes. Journal of Applied Meteorology and Climatology, DOI: 10.1175/JAMC-D-17-0093.1
2018.

Madani, N., Kimball, J. S., Ballantyne, A. P., Affleck, D. L., Bodegom, P. M., Reich, P. B., ... & Zhao, M. (2018). Future global productivity will be affected by plant trait response to climate. Scientific reports, 8(1), 2870.

Ballantyne, Ashley,William Smith,William Anderegg, Pekka Kauppi, Jorge Sarmiento, Pieter Tans, Elena Shevliakova, Yude Pan, Benjamin Poulter, Alessandro Anav,Pierre Friedlingstein, Richard Houghton, and Steven Running. (2017) Accelerating net terrestrial carbon uptake during the warming hiatus due to reduced respiration. *Nature Climate Change*, doi: 0.1038/2034

Wang, J., J. Dong, Y. Yi, G. Lu, J. Oyler, W. K. Smith, M. Zhao, J. Liu, and S. Running. (2017). Decreasing net primary production due to drought and slight decreases in solar radiation in China from 2000 to 2012. *J. Geophys. Res. Biogeosci.*, 122, 261–278, doi:10.1002/2016JG003417.

Hidy, Dóra, Zoltán Barcza, Hrvoje Marjanovi, Maša Zorana Ostrogovi Sever, Laura Dobor, Györgyi Gelybó, Nándor Fodor, Krisztina Pintér, Galina Churkina, Steven Running, Peter Thornton, Gianni Bellocchi, László Haszpra, Ferenc Horváth, Andrew Suyker, and Zoltán

Nagy. (2016). Terrestrial ecosystem process model Biome-BGCMuSo v4.0: summary of improvements and new modeling possibilities. *Geosci. Model Dev*., 9, 4405–4437.

Sanchez-Ruiz, Sergio, Alvaro Moreno, Maria Piles, Fabio Maselli, Arnaud Carrara, Steven Running, and Maria Amparo Gilabert. (2016). Quantifying water stress effect on daily light use efficiency in Mediterranean ecosystems using satellite data. *International Journal of Digital Earth*, DOI: 10.1080/17538947.2016.1247301.

Ahrestani, Farshid S., Mark Hebblewhite, William Smith, Steven Running, and Eric Post. (2016). Dynamic complexity and stability of herbivore populations at the species distribution scale. *Ecology*, 97(11): 3184-3194.

Yu, Zhen, Jingxin Wang, Shirong Liu, Shilong Piao, Philippe Ciais, Steven W. Running, Benjamin Poulter, James S. Rentch and Pengsen Sun. (2016) Decrease in winter respiration explains 25% of the annual northern forest carbon sink enhancement over the last 30 years. *Global Ecology and Biogeography*, doi: 10.1111/geb.12441.

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Zhang, KE, John S. Kimball, and Steven W. Running. (2016) A review of remote sensing based actual evapotranspiration estimation. *WIREs Water*, doi: 10.1002/wat2.1168.

Oyler, J.W., S.Z. Dobrowski, Z.A. Holden, and S.W. Running. (2016) Remotely sensed land skin temperature as a spatial predictor of air temperature across the conterminous United States. *J. Appl. Meteorol. Climatol.*,http://dx.doi.org/10.1175/JAMC-D-15-0276.1.

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Oyler, J. W., Dobrowski S. Z., Ballantyne A. P., Klene A. E., and Running S. W. (2015) Artificial amplification of warming trends across the mountains of the western United States. *Geophysical Research Letters*, 01/2015, 42(1).

Running, S. W. (2014) A regional look at HANPP: human consumption is increasing, NPP is not. *Environmental Research Letters*, 11/2014, 9(11).

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Madani, N., Kimball J. S., Affleck D. L. R., Kattge J., Graham J. S., van Bodegom P. M., Reich P. B., and Running S. W. (2014) Improving ecosystem productivity modeling through spatially explicit estimation of optimal light use efficiency. *Journal of Geophysical Research: Biogeosciences*, 08/2014, 119: 1–15.

Hansen, A.J. N. Piekielek, C. Davis, J. Haas, D. M. Theobald, J. E. Gross, W.B Monahan, T. Oliff, and S. W. Running. (2014). Exposure of U.S. National Parks to land use and climate change 1900 – 2100. *Ecological Applications*, 24(3): 484-502.

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Oyler, J.W., A.P.Ballantyne, K. Jencso, M.Sweet, and S.W.Running. (2014) Creating a daily air temperature dataset for the conterminous United States using homogenized station data and remotely sensed skin temperature. *Int. J. Climatology*, DOI 10.1002/joc.4127.

Reeves, M. C., Moreno A. L., Bagne K. E., and Running S. W. (2014) Estimating climate change effects on net primary production of rangelands in the United States. *Climatic Change*, 09/2014, 126(3-4).

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Ruhoff, A. L.; Paz, A. R.; Aragao, L. E. O. C.; Mu, Q., and Running, S.W. (2013) Assessment of the MODIS global evapotranspiration algorithm using eddy covariance measurements and hydrological modelling in the Rio Grande basin. *Hydrological sciences journal*, 58(8): 1658-1676.

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Mills, L. Scott; Zimova, Marketa; Oyler, Jared; and Running, S.W. (2013) Camouflage mismatch in seasonal coat color due to decreased snow duration. *Proceedings of the National Academy of Sciences*, 110: 7360-7365.

Bohn, Theodore J.; Livneh, Ben; Oyler, Jared W.; Running, S.W. (2013) Global evaluation of MTCLIM and related algorithms for forcing of ecological and hydrological models. *Agricultural and Forest Meterology*, 176: 38-49.

Cleveland, C.C., B.Z Houlton, WKSmith, AR Marklein, S.C Reed, W.P.Parton, S.J.DelGrasso, and S.W.Running (2013) Patterns of new versus recycled primary production in the terrestrial biosphere. *Proc Nat Acad Sci*, 110: 12733 - 12737.

Running,S.W. (2013). Book Review: Approaching the Limits. *Science*, 339: 1276-1277.

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Tallis, H. H. Mooney, S. Andelman, P. Balvanera, W. Cramer, D. Karp, S. Polasky, B. Reyers, T. Ricketts, S. Running, K. Thonicke, B. Tietjen, and A. Walz. (2012) A global system for monitoring ecosystem service change. *Bioscience*, 62: 977-986

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Hasenauer, H., Petritsch R., Zhao M**.**, Boisvenue C., and Running S. W**.** (2012) Reconciling satellite with ground data to estimate forest productivity at national scales. *Forest Ecology and Management*, 276: 196-208.

Smith, W. K., Zhao M., and Running S. W. (2012) Global Bioenergy Capacity as Constrained by Observed Biospheric Productivity Rates, *BioScienc*e, 62:10:911–922.

Leppi, J. C., DeLuca T. H., Harrar S. W., and Running S. W. (2012) Impacts of climate change on August stream discharge in the Central-Rocky Mountains. *Climatic Change*, 06/2012, 112(3-4): 997–1014.

Smith, W. K., Cleveland C. C., Reed S. C., Miller N. L., and Running S. W. (2012) Bioenergy Potential of the United States Constrained by Satellite Observations of Existing Productivity. *Environmental Science and Technology*, 02/2012.

Mu, Q., Zhao M., and Running S. W. (2011) Evolution of hydrological and carbon cycles under a changing climate. *Hydrological Processes*, 11/2011, 25: 4093–4102.

Mildrexler, D. J., Zhao M., and Running S. W. (2011) Satellite Finds Highest Land Skin Temperatures on Earth. *Bulletin of the American Meteorological Society*, July, 92: 855–860.

Mildrexler, D. J., Zhao M., and Running S. W. (2011) A global comparison between station air temperatures and MODIS land surface temperatures reveals the cooling role of forests, *Journal of Geophysical Research,* Aug. 16(G03025).

Zhao, M., and Running S. W. (2011) Response to Comments on "Drought induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009". *Science*, Aug, 333(6046): 1093.

Zhao, M., Running S. W., Heinsch F. A., and Nemani R. R. (2011) MODIS-Derived Terrestrial Primary Production. *Land Remote Sensing and Global Environmental Change: NASA's Earth Observing System and the Science of ASTER & MODIS*, p.635-660.

Mu, Q., M. Zhao, and S.W. Running. (2011) Improvements to a MODIS global terrestrial evapotranspiration algorithm. *Remote Sensing of Environment*, 115: 1781-1800.

Zhao, M., and S.W. Running. (2010) Drought Induced Reduction in Global Terrestrial Net Primary Production from 2000 through 2009. *Science*, 329: 940-943.

Boisvenue, C., and S. Running. (2010) Simulations show decreasing carbon stocks and potential for carbon emissions for Rocky Mountain forests in the next century. *Ecological Applications*, 20(5): 1302-1319.

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Running, S.W.R. (2010) EOS Is More Important Than Ever. *Earthwide Communications LLC*.

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Le Quere, C., M.R. Raupach, J. G. Canadell, G. Marland, L. Bopp, P. Ciais, T. J. Conway, S.C. Doney, R.A. Feely, P. Foster, P. Friedlingsten, K. Gurney, R.A. Houghton, J.I. House, C. Huntingford, P.E. Levy, M.R. Lomas, J. Majkut, N. Metzl, J. P. Ometto, G.P. Peters, C. Prentice, J.T. Randerson, S.W.R. Running, J.L. Sarmiento, U. Schuster, S. Sitch, T. Takahashi, N. Viovy, G.R. van der Werf, and F.I. Woodward. (2009) Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, 1-6.

Running, S.W., R.R.Nemani, J.R.G.Townshend, and D.D.Baldocchi. (2009) Next Generation Terrestrial Carbon Monitoring. IN: *Carbon Sequestration and Its Role in the Global Carbon Cycl*e. American Geophysical Union. Geophysical Monograph Series 183: 49-69.

Nightingale, J., and S. W. Running. (2009) Long Term Global Monitoring of Vegetation Variables Using Moderate Resolution Satellites. *EOS*, 90(27): 388.

Zhang, K., J.S. Kimball, Q. Mu, L.A. Jones, S.J. Goetz, and S.W. Running. (2009) Satellite based analysis of northern ET trends and associated changes in the regional water balance from 1938 to 2005. *Journal of Hydrology*, 379: 92-110.

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Mildrexler, D.J., M. Zhao, and S.W. Running. (2009) Testing a MODIS Global Disturbance Index across North America. *Remote Sensing of Environment*, 113: 2103-2117.

Renzullo, L.J., D.J. Barrett, A.S. Marks, M.J. Hill, J.P. Guerschman, Q. Mu, and S.W. Running. (2008) Multi-sensor model-data fusion for estimation of hydrologic and energy flux parameters. *Remote Sensing of Environment*, 112: 1306-1319.

Stockli, R., D.M. Lawrence, G.–Y. Niu, K.W. Oleson, P.E.Thornton, Z.-L. Yang, G.B. Bonan, A.S. Denning, and S.W. Running. (2008) Use of FLUXNET in the Community Land Model development. *Journal of Geophysical Research*, 113: G01025.

Hashimoto, H., J.L. Dungan, M. A. White, F. Yang, A. R. Michaelis, S. W. Running, and R. R. Nemani. (2008) Satellite-based estimation of surface vapor pressure deficits using MODIS land surface temperature data. *Remote Sensing of Environment*, 112: 42-155.

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Zhao, M., and S. W. Running. (2008) Remote Sensing of Terrestrial Primary Production and Carbon Cycle *Advances in Land Remote Sensing: System, Modeling, Inversion and Applicatio*n, S. Liang (Ed.), Springer 423-444.

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Zhang, K., J. S. Kimball, E.H. Hogg, M. Zhao, W. C. Oechel, J. Cassano, and S. W. Running. (2008) Satellite-based model detection of recent climate-driven changes in northern high-latitude vegetation productivity. *Journal of Geophysical Research*, 113: G03033.

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Kimball, J. S., M. Zhao, A. D. McGuire, F. A. Heinsch, J. Clein, M. Calef, W. M. Jolly, S. Kang, S. E. Euskirchen, K. C. McDonald, S. W. Running. (2007) Recent Climate-Driven Increases in Vegetation Productivity for the Western Arctic: Evidence of an Acceleration of the Northern Terrestrial Carbon Cycle. *Earth Interactions* 11(4):1-30.

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Mildrexler, D.J., M. Zhao, F.A. Heinsch, and S.W. Running. (2007) A new satellite-based methodology for continental-scale disturbance detection. *Ecological Applications*, 17(1): 235-250.

Reichstein, M., P. Ciais, D. Papale, R. Valentini, S. Running, N. Viovys, W. Cramer, A. Granier, J. Ogee, V. Allard, M. Aubinet, Chr. Bernhofer, N. Buchmann, A. Carrara, T. Grünwald, M. Heimann, B. Heinesch, A. Knohl, W. Kutsch, D. Loustau, G. Manca, G. Matteucci, F. Miglietta, J.M. Ourcival, K. Pilegaard, J. Pumpanen, S. Rambal, S. Schaphoff, G. Seufert, J.F. Soussana, M.J. Sanz, T. Vesala, and M. Zhao. (2007) Reduction of ecosystem productivity and respiration during the European summer 2003 climate anomaly: a joint flux tower, remote sensing and modelling analysis. *Global Change Biology*, 13: 634.

EXHIBIT C:

STATEMENT OF PREVIOUS TESTIMONY WITHIN PRECEDING FOUR YEARS

In 2017, I provided expert testimony in *State of Washington v. Taylor*, Case No: 6Z0117975 (Spokane Cnty. District Court 2017). In 2015, I provided expert testimony in *City of Missoula v. Mountain Water Co.*, 378 P.3d 1113 (Mont. 2016).

EXHIBIT D: REFERENCES

Abatzoglou JT, Williams AP. 2016. Impact of anthropogenic climate change on wildfire across western US forests. *Proceedings of the National Academy of Sciences* 113(42): 11770–11775. DOI: 10.1073/pnas.1607171113.

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EXHIBITS E–G: VIDEO EXHIBITS

Exhibits F–G are video exhibits, attached hereto via Dropbox. Exhibit E is a spreadsheet providing the precise data and information for Exhibits F–G, and is also attached hereto via Dropbox.