Human-Caused Climate Change in the United States National Parks

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Testimony to the United States House of Representatives

Committee on Natural Resources, Subcommittee on National Parks, Forests, and Public Lands

February 13, 2019

Executive Summary

From wildfires burning in Yosemite National Park, California, to glaciers melting in Glacier Bay National Park, Alaska, published scientific research has detected changes globally and in United States (U.S.) national parks and attributed them to human-caused climate change. These impacts are occurring because climate change since 1895 has exposed the national parks to twice the heating of the country as a whole and to more severe aridity. Without cuts to pollution from cars, power plants, deforestation, and other human sources, continued climate change could increase future temperatures up to six times faster than historical rates, threatening the unique landscapes, plants, and animals in parks. Adaptation of resource management could decrease some projected damage. Yet, cutting carbon pollution from human sources is the solution that targets the cause of climate change. Emissions reductions could lower projected heating in national parks by one-half to two-thirds. The lowered heating would reduce risks of severe wildfire, disappearances of plant and animal species, and other threats to our national parks.

Introduction

Chairwoman, Ranking Member, and Members of the Committee, thank you for the invitation to speak on the science of human-caused climate change in the U.S. national parks. I am Patrick Gonzalez, a forest ecologist and Associate Adjunct Professor at the University of California, Berkeley, in the Department of Environmental Science, Policy, and Management. I am also the Principal Climate Change Scientist of the U.S. National Park Service, but today I am speaking under my Berkeley affiliation, not for the Park Service. I earned my Ph.D. at the University of California, Berkeley, and have conducted and published field research on climate change for 25 years. I have also served for over eight years as the lead for climate change science in the U.S. National Park Service. I am a lead author on four reports of the Intergovernmental Panel on Climate Change (IPCC), the organization that produces the authoritative scientific assessments of climate change, for which it was awarded a share of the 2007 Nobel Peace Prize.

Human Cause of Climate Change

The human cause of climate change[1] is an important scientific fact because it points us to solutions to the problem. Atmospheric measurements show that carbon dioxide has increased to its highest level in 800 000 years (Figure 1).[2-5] Measurements show that the increased carbon dioxide and other greenhouse gases in the atmosphere come from cars, power plants, deforestation, and other human sources.[6] Chemical analyses show that the additional carbon dioxide bears the unique chemical signature of fossil fuels – coal, oil, and gas – not of natural emissions from volcanoes.[7] Human sources now emit twice the amount of carbon dioxide that vegetation, soils, and the oceans can naturally absorb.[6] This is the fundamental imbalance that causes climate change.

The increase in carbon dioxide has intensified the greenhouse effect, the trapping of heat close to the surface of the Earth. Consequently, the world has heated to its highest temperature in 800 years.[8] Measurements of the potential causal factors – human and natural – show that carbon dioxide and other greenhouse gases from human activities caused 97% of historical heating.[9] Solar cycles and other natural factors caused just the remaining 3%. Therefore, scientific evidence shows that human activities are causing climate change.

Historical Impacts in U.S. National Parks

The magnitude of climate change across all the U.S. national parks was not known until recent research by colleagues and me. In 2018, we published the first spatial analyses of temperature and precipitation trends across all 417 U.S. national parks.[10] Our analyses of historical data revealed that climate change has exposed the national parks to conditions hotter and drier than the country as a whole. This occurs because extensive parts of the parks are in extreme environments – the Arctic, high mountains, and the arid Southwest.

Our findings show that temperatures in the national park area increased at a rate of 1ºC (approximately 2ºF.) per century from 1895 to 2010, double the national rate. At the same time, precipitation decreased across a greater fraction of the national park area (12%) than the country as a whole (3%). Out of all 417 national parks, temperatures increased most in Denali National Preserve, Alaska (4.3ºC [approximately 8ºF.] per century) (Figure 2), and rainfall declined most in Honouliuli National Monument, Hawaii (85% decrease per century).

The implications of this increased heat and aridity in the national parks were not comprehensively known until recently. In 2017, I published the first comprehensive assessment of published research on climate change impacts and vulnerabilities in U.S. national parks.[11] This section on historical impacts provides cases from that publication, only including research that has employed the research procedures of detection and attribution.[1]

Detection is the finding of statistically significant changes over time that are different than natural variation. Attribution is the analysis of different potential causes, natural and human, to determine their relative importance. In many national parks, it is easier to tell if human-caused climate change is the main cause of changes in the field because many parks have been protected from urbanization, timber harvesting, grazing, and other non-climate disturbances.

Historical impacts detected and attributed to human-caused climate change include:

Glaciers melting In Glacier Bay National Park (NP), Alaska, climate change melted 640 meters (2100 ft.) of ice (depth) from Muir Glacier from 1948 to 2000 (Figure 3).[12,13] In Glacier NP, Montana, climate change melted 1.5 km (1 mi.) of ice (length) from Agassiz Glacier from 1926 to 1979.[13,14] In the North Cascades NP complex, Washington, climate change melted four glaciers away completely from 1984 to 2004.[13,15]

Snowpack decline Across the western U.S., including North Cascades NP, Washington, and ten other national parks, climate change has melted snowpack to its lowest level in eight centuries.[16]

Wildfire increase Across the western U.S., including Yellowstone NP, Wyoming, and Yosemite NP, California, climate change doubled the area burned by wildfire from 1984 to 2015, compared to the area of natural burning.[17] Wildfire is a natural part of many ecosystems but excessive wildfire can damage ecosystem integrity and hurt people. Across the western U.S., climate was the dominant factor controlling burning from 1916 to 2003, even during periods of active fire suppression.[18]

Tree death Across the western U.S., including Kings Canyon NP, Lassen Volcanic NP, Sequoia NP, and Yosemite NP, California, Mount Rainier NP, Washington, and Rocky Mountain NP, Colorado, climate change doubled tree mortality from 1955 to 2007 [19], due to increased aridity,[19,20] the most extensive bark beetle infestations in a century, [19-22] and increased wildfire.[20]

Vegetation shifts In Yosemite NP, California, climate change shifted subalpine forest upslope into subalpine meadows between 1880 and 2002.[23] In Noatak National Preserve, Alaska, climate change shifted boreal conifer forest northward onto formerly treeless tundra between 1800 and 1990.[24] Climate change, by shifting warmer conditions upslope and farther north, has shifted major vegetation types (biomes) at sites around the world.[25]

Wildlife shifts In Yosemite NP, California, field research showed that climate change shifted the ranges of the American pika, a small alpine mammal, and other species 500 meters upslope (approximately 1600 ft.) from 1920 to 2006, when temperature increased 3ºC (approximately 5ºF.)[26] Because the national park had protected the survey area, timber harvesting, grazing, and hunting were not major factors.

Analyses of Audubon Christmas Bird Count data across the U.S., including sites in numerous national parks, found that climate change shifted the average winter range of 254 bird species northward 15 km (9 mi.) from 1975 to 2004.[27] Because of this, the evening grosbeak disappeared from counts in Sleeping Bear Dunes National Lakeshore, Michigan, and Shenandoah NP, Virginia.

Sea level rise Climate change has raised sea level 22 cm (9 in.) since 1854 at Golden Gate National Recreation Area, San Francisco, California,[28-30] 42 cm (17 in.) since 1856 at New York City,[29-31] not far from the Statue of Liberty National Monument, and 30 cm (12 in.) since 1924 at Washington, DC,[29,30,32] not far from the Jefferson Memorial and the White House, which is a national park.

Coral bleaching Climate change bleached and killed up to 80% of coral reef area in 2005 at sites in Biscayne NP, Florida, and Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, Virgin Islands National Park, and Virgin Islands Coral Reef National Monument.[33,34] That year, climate change had caused the hottest sea surface temperatures recorded in the Caribbean Sea since 1855.

Future Vulnerabilities

To quantify potential future changes in national parks, colleagues and I analyzed all available climate projections from the Intergovernmental Panel on Climate Change, as part of the first spatial analysis of climate trends across all 417 U.S. national parks.[10] Our results indicate that continued carbon emissions under the worst scenario could increase temperatures in the 21st century six times faster than occurred in the 20th century. Temperatures in national parks could increase up to 9ºC (16ºF.) by 2100, in the national parks of Alaska, and rainfall could decline by as much as 28 percent, in the national parks of the U.S. Virgin Islands. Aridity could also increase in Big Bend NP, Texas, Everglades NP, Florida, and other national parks at southern latitudes.

Published research on U.S. national park resources indicates that continued climate change could damage many of the globally unique ecosystems and resources that the parks protect. These vulnerabilities include:

Loss of glaciers Climate change could cause, under the worst scenario, complete melting of glaciers from Glacier National Park, Montana, by the 2030s[35] and the disappearance of Sperry Glacier from Rocky Mountain NP by the 2040s.[36]

Wildfire increase The hotter temperatures of climate change could, under a high emissions scenario, increase wildfire frequencies in Yellowstone NP and Grand Teton NP, Wyoming, 300% to 1000% [37] and up to 300% in Yosemite NP, California, by 2100.[38]

Tree death The more severe aridity of climate change could, under a high emissions scenario, reduce suitable habitat of the Joshua tree in the southwestern U.S. 90% by 2100, leading to extensive death of Joshua trees in Joshua Tree NP, California.[39,40] The more severe aridity of climate change also increases the risk of higher mortality of foothills palo verde and ocotillo in Saguaro NP, Arizona,[41] piñon pine in Bandelier National Monument, New Mexico,[42] and coast redwoods, the tallest living things on Earth, in Muir Woods National Monument, California.[43,44] Loss of snow under projected climate change increases the vulnerability of Alaska yellow cedar to increased mortality in Sitka National Historical Park, Alaska.[45] Under projected climate change, 16% to 41% of total national park area is highly vulnerability to northward and upslope vegetation shifts (biome shifts).[25]

Loss of wildlife Climate change may shift habitats upslope to such an extent that the American pika, a small alpine mammal that lives at the highest elevations, could disappear from Lassen Volcanic NP, California.[46] Climate change could also exacerbate cheatgrass invasions in Craters of the Moon National Monument and Preserve, Idaho, leading to substantial decline of the sage grouse.[47,48] Numerous national parks could lose local bird species and be colonized by new migrants.[49] At Canaveral National Seashore, Florida, green turtles are vulnerable to increased mortality from flooding of nests by increases in storms.[50]

Inundation from sea level rise Sea level rise due to climate change could inundate much of Everglades National Park, Florida,[51] the center of Golden Gate National Recreation Area, California,[52,53] the National Mall and other national parks in Washington, DC,[54] one-third of the area of Assateague Island National Seashore, Maryland,[55] and the Statue of Liberty National Monument, New York.[56]

Ocean acidification Corals and other marine life in Dry Tortugas National Park, Florida,[57] and Channel Islands NP and Cabrillo National Monument, California,[58] are vulnerable to dissolving in acidified waters under continued climate change.

Adaptation of Natural Resource Management

Adaptation to climate change is the adjustment of practices in a way that moderates future harm. One adaptation measure under implementation in a national park is the protection of refugia for the Joshua tree in Joshua Tree NP, California.[40] Other adaptation measures under consideration for parks include conservation of refugia for mountain plants and animals,[59,60] and conservation of cooler water refugia for fish.[61] Prescribed burning is an adaptation measure that reduces future risks of catastrophic wildfire and tree death by removing an unnatural buildup of fuel and small trees where old policies suppressed natural wildfire.[62,63] While adaptation measures are important to help maintain ecosystem integrity, they only treat symptoms of climate change, not the cause.

Carbon Solutions

Published research by colleagues and me concludes that reducing the cause of climate change – carbon pollution from cars, power plants, deforestation, and other human sources – can save national parks from the most extreme heat in the future.[10] Compared to the worst scenario, reduced carbon emissions would lower projected heating in national parks by one-half to two-thirds by 2100.

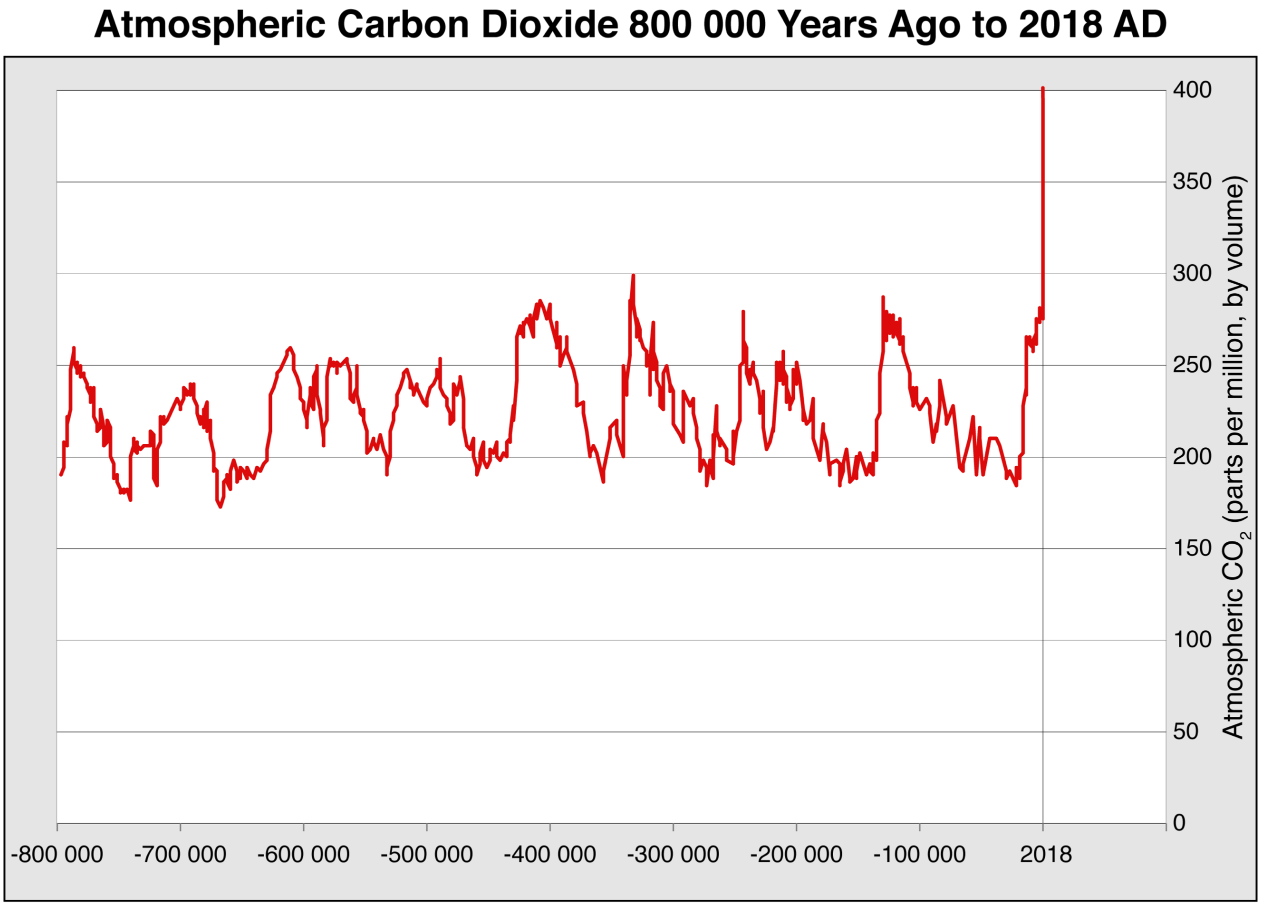
The reduced heating could produce real benefits on the ground. While under the worst emissions scenario, 16% of plant and animal species globally could be at risk of extinction,[64] the risk drops to 5% under the lowest emissions scenario of meeting the Paris Agreement goal.[65] Similarly, global sea level could rise 74 cm (29 in.) under the worst emissions scenario, but rise 44 m (17 in.) under the Paris Agreement goal.[29] In Yosemite NP, California, climate change under the worst emissions scenario could triple burned area by 2100, but a low emissions scenario could keep wildfires near to their current level.[38]

A supplemental carbon solution is the conservation of forests, which naturally reduce climate change by removing carbon dioxide from the atmosphere and storing it in leaves and wood. Coast redwood forest near Redwood NP, California, contains more carbon per area on the ground than any other forest in the world.[66] The 27 national parks in California together contain as much carbon as the annual emissions of 7.4 million Americans, or the combined population of the cities of Boston, Charlotte, Dallas, Kansas City, Los Angeles, and Miami.[67] This is a substantial amount of carbon, but those millions of people can burn the equivalent of all the carbon in the coast redwoods and other vegetation in the national parks in California in just one year. Therefore, forest conservation is insufficient as a sole solution to climate change. This points to the need for reducing emissions from fossil fuel burning.

Analyses by the IPCC recently confirmed that it is still possible to limit future heating to the Paris Agreement goal of a temperature increase less than 2ºC (approximately 4ºF.)[68] The U.S. has already demonstrated its ability to cut emissions. From 2007 to 2015, the U.S. cut emissions 8%.[69] From 2005 to 2016, the U.S. Climate Alliance of 19 states and one territory cut its emissions 14%, on track to meet the Paris Agreement goal.[70] We have achieved this progress through energy conservation, improved efficiency, renewable energy, public transit, and other available practices.

The U.S. national parks protect some of the most irreplaceable natural areas and cultural sites in the world. Cutting carbon pollution would reduce human-caused climate change and help save our national parks for future generations.

Figure 1. Atmospheric carbon dioxide 800 000 years ago to 2018 AD.



Data: Petit et al. 1999 Nature, Monnin et al. 2001 Science, Lüthi et al. 2008 Nature, Bereiter et al. 2015 Geophysical Research Letters, C.D. Keeling, National Oceanic and Atmospheric Administration; Graph: P. Gonzalez

Figure 2. Temperature change from 1895 to 2010 due to human-caused climate change.
Map: Trend in annual temperature in degrees Celsius per century, with park boundaries in green.
Graph: Statistically significant trend for the area of the 417 US national parks.

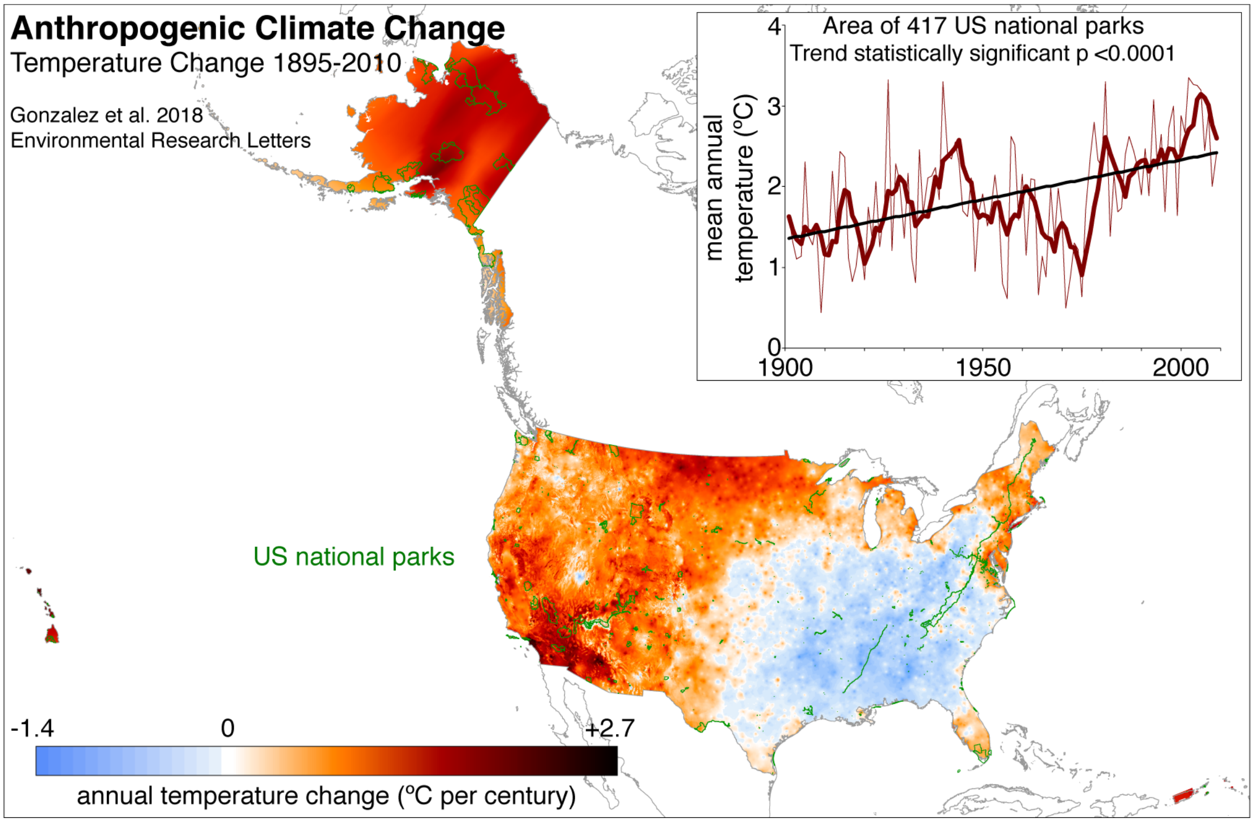
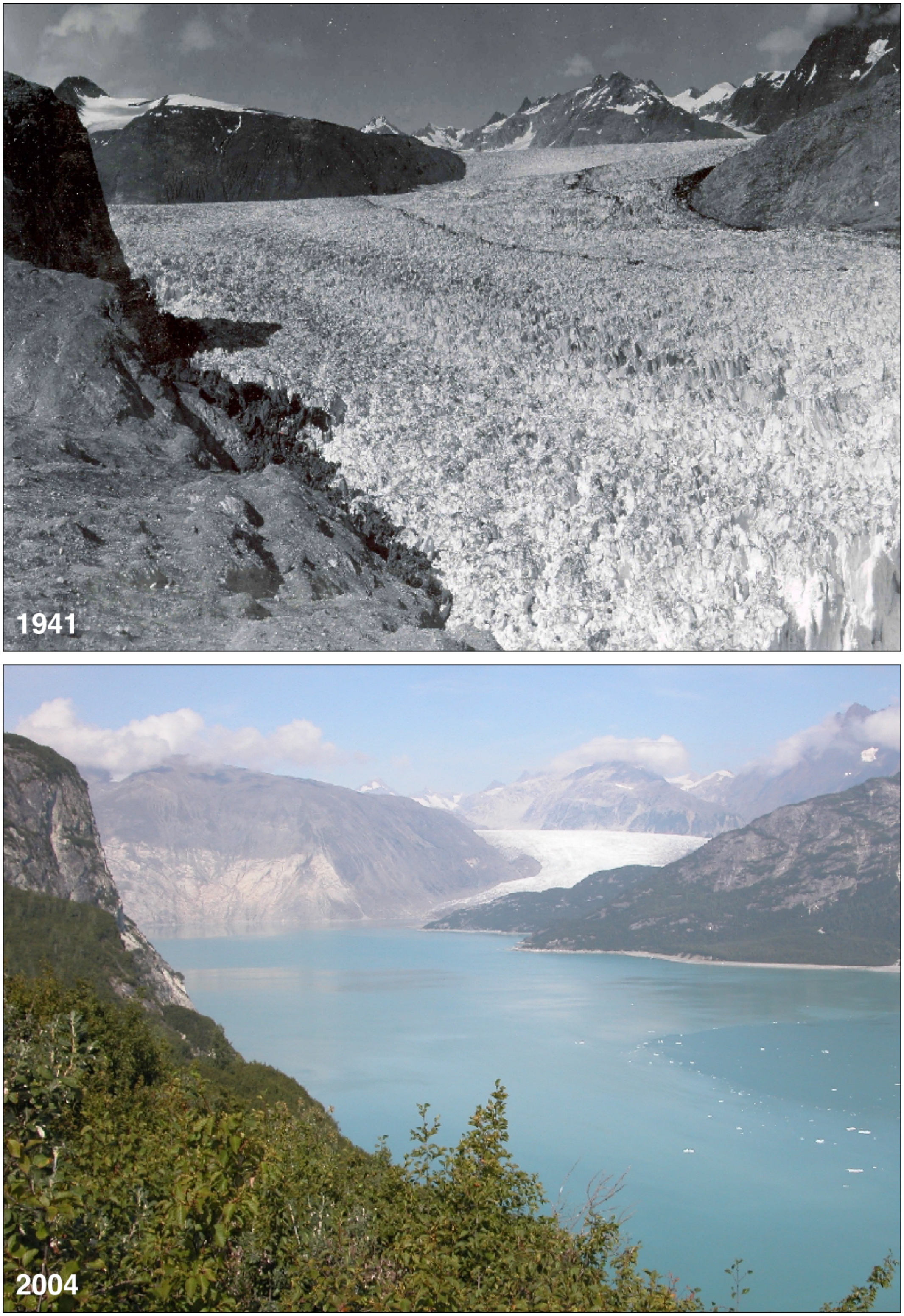


Figure 3. Melting of Muir Glacier, Glacier Bay National Park, Alaska.

Top: August 13, 1941 (photo by William O. Field, U.S. Geological Survey).

Bottom: August 31, 2004 (photo by Bruce F. Molnia, U.S. Geological Survey).



Scientific References

1. Bindoff, N.L. et al. 2013. Detection and attribution of climate change: From global to regional. In Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. [Stocker, T.F. et al. (eds.)] Cambridge University Press, Cambridge, UK.
2. Petit J.R. et al. 1999. Climate and atmospheric history of the past 420 000 years from the Vostok Ice Core, Antarctica. Nature 399: 429-436.
3. Monnin, E. et al. 2004. Evidence for substantial accumulation rate variability in Antarctica during the Holocene, through synchronization of CO_2 in the Taylor Dome, Dome C, and DML ice cores. Earth and Planetary Science Letters 224: 45-54.
4. Lüthi, D. et al. 2008. High-resolution carbon dioxide concentration record 650,000-800,000 years before present. Nature 453: 379-382.
5. Bereiter, B., S. Eggleston, J. Schmitt, C. Nehrbass-Ahles, T.F. Stocker, H. Fischer, S. Kipfstuhl, and J. Chappellaz. 2015. Revision of the EPICA Dome C CO_2 record from 800 to 600 kyr before present. Geophysical Research Letters 42: 542–549.
6. Ciais, P. et al. 2013. Carbon and other biogeochemical cycles. In Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. [Stocker, T.F. et al. (eds.)] Cambridge University Press, Cambridge, UK.
7. Denman, K.L. et al. 2007. Couplings between changes in the climate system and biogeochemistry. In Intergovernmental Panel on Climate Change. Climate Change 2007: The Physical Science Basis. [Solomon, S. et al. (eds.)] Cambridge University Press, Cambridge, UK.
8. Masson-Delmotte, V. et al. 2013. Information from paleoclimate archives. In Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. [Stocker, T.F. et al. (eds.)] Cambridge University Press, Cambridge, UK.
9. Myhre, G. et al. 2013. Anthropogenic and natural radiative forcing. In Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. [Stocker, T.F. et al. (eds.)] Cambridge University Press, Cambridge, UK.
10. Gonzalez, P., F. Wang, M. Notaro, D.J. Vimont, and J.W. Williams. 2018. Disproportionate magnitude of climate change in United States national parks. Environmental Research Letters 13: 104001. doi:10.1088/1748-9326/aade09.
11. Gonzalez, P. 2017. Climate change trends, impacts, and vulnerabilities in US national parks. In Beissinger, S.R., D.D. Ackerly, H. Doremus, and G.E. Machlis (eds.) Science, Conservation, and National Parks. University of Chicago Press, Chicago, IL.
12. Larsen, C.F., R.J. Motyka, A.A. Arendt, K.A. Echelmeyer, and P.E. Geissler. 2007. Glacier changes in southeast Alaska and northwest British Columbia and contribution to sea level rise. Journal of Geophysical Research 112: F01007. doi:10.1029/2006JF000586.
13. Marzeion, B., J.G. Cogley, K. Richter, and D. Parkes. 2014. Attribution of global glacier mass loss to anthropogenic and natural causes. Science 345: 919-921.
14. Pederson, G.T., D.B. Fagre, S.T. Gray, and L.J. Graumlich. 2004. Decadal-scale climate drivers for glacial

dynamics in Glacier National Park, Montana, USA. Geophysical Research Letters 31: L12203. doi:10.1029/2004GL019770.

15. Pelto, M.S. 2006. The current disequilibrium of North Cascade glaciers. Hydrological Processes 20: 769-779.
16. Pederson, G.T., S.T. Gray, C.A. Woodhouse, J.L. Betancourt, D.B. Fagre, J.S. Littell, E. Watson, B.H. Luckman, and L.J. Graumlich. 2011. The unusual nature of recent snowpack declines in the North American Cordillera. Science 333: 332-335.
17. Abatzoglou, J.T. and A.P. Williams. 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proceedings of the National Academy of Sciences of the USA 113: 11 770-11 775.
18. Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications 19: 1003-1021.
19. van Mantgem, P.J., N.L. Stephenson, J.C. Byrne, L.D. Daniels, J.F. Franklin, P.Z. Fule, M.E. Harmon, A.J. Larson, J.M. Smith, A.H. Taylor, and T.T. Veblen. 2009. Widespread increase of tree mortality rates in the western United States. Science 323: 521-524.
20. Berner, L.T., B.E Law, A.J.H. Meddens, and J.A. Hicke. 2017. Tree mortality from fires, bark beetles, and timber harvest during a hot and dry decade in the western United States (2003–2012). Environmental Research Letters 12: 065005. doi:10.1088/1748-9326/aa6f94.
21. Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. BioScience 58: 501-517.
22. Macfarlane, W.W., J.A. Logan, and W.R. Kern. 2013. An innovative aerial assessment of Greater Yellowstone Ecosystem mountain pine beetle-caused whitebark pine mortality. Ecological Applications 23: 421-437.
23. Millar, C.I., R.D. Westfall, D.L. Delany, J.C. King, and L.J. Graumlich. 2004. Response of subalpine conifers in the Sierra Nevada, California, U.S.A., to 20th-Century warming and decadal climate variability. Arctic, Antarctic, and Alpine Research 36: 181-200.
24. Suarez, F., D. Binkley, M.W. Kaye, and R. Stottlemyer. 1999. Expansion of forest stands into tundra in the Noatak National Preserve, northwest Alaska. Ecoscience 6: 465-470.
25. Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. Global Ecology and Biogeography 19: 755-768.
26. Moritz, C., J.L. Patton, C.J. Conroy, J.L. Parra, G.C. White, and S.R. Beissinger. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322: 261-264.
27. La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. Ecology 88: 1803-1812.
28. National Oceanic and Atmospheric Administration. 2019. Relative sea level trend 9414290 San Francisco, California. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9414290.
29. Church, J.A. et al. 2013. Sea level change. In Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. [Stocker, T.F. et al. (eds.)] Cambridge University Press, Cambridge, UK.
30. Slangen, A.B.A, J.A. Church, C. Agosta, X. Fettweis, B. Marzeion, and K. Richter. 2016. Anthropogenic

forcing dominates global mean sea-level rise since 1970. Nature Climate Change 6: 701-705.
31. National Oceanic and Atmospheric Administration. 2019. Relative sea level trend 8518750 The Battery, New York. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8518750.
32. National Oceanic and Atmospheric Administration. 2019. Relative sea level trend 8594900 Washington, District of Columbia. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8594900.
33. Eakin, C.M. et al. 2010. Caribbean corals in crisis: Record thermal stress, bleaching, and mortality in 2005. PLoS ONE 5: e13969. doi:10.1371/journal.pone.0013969.
34. Cramer, W. et al. 2014. Detection and attribution of observed impacts. In Intergovernmental Panel on Climate Change. Climate Change 2014: Impacts, Adaptation, and Vulnerability. [Field, C.B. et al. (eds.)] Cambridge University Press, Cambridge, UK.
35. Hall, M.H.P. and D.B. Fagre. 2003. Modeled climate-induced glacier change in Glacier National Park, 1850-2100. Bioscience 53: 131-140.
36. Brown, J., J. Harper, and N. Humphrey. 2010. Cirque glacier sensitivity to 21st century warming: Sperry Glacier, Rocky Mountains, USA. Global and Planetary Change 74: 91-98.
37. Westerling, A.L., M.G. Turner, E.A.H. Smithwick, W.H. Romme, and M.G. Ryan. 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. Proceedings of the National Academy of Sciences of the USA 108: 13165-13170.
38. Westerling, A.L., B.P. Bryant, H.K. Preisler, T.P. Holmes, H.G. Hidalgo, T. Das, and S.R. Shrestha. 2011a. Climate change and growth scenarios for California wildfire. Climatic Change 109: S445-463.
39. Cole, K.L., K. Ironside, J. Eischeid, G. Garfin, P.B. Duffy, and C. Toney. 2011. Past and ongoing shifts in Joshua tree distribution support future modeled range contraction. Ecological Applications 21: 137-149.
40. Barrows, C.W. and M.L. Murphy-Mariscal. 2012. Modeling impacts of climate change on Joshua trees at their southern boundary: How scale impacts predictions. Biological Conservation 152: 29-36.
41. Munson, S.M., R.H. Webb, J. Belnap, J.A. Hubbard, D.E. Swann, and S. Rutman. 2012. Forecasting climate change impacts to plant community composition in the Sonoran Desert region. Global Change Biology 18: 1083-1095.
42. Williams, A.P. et al. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change 3: 292-297.
43. Johnstone, J.A. and T.E. Dawson. 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences of the USA 107: 4533-4538.
44. Fernández, M., H.H. Hamilton, and L.M. Kueppers. 2015. Back to the future: Using historical climate variation to project near-term shifts in habitat suitable for coast redwood. Global Change Biology 21: 4141-4152.
45. Buma, B., P.E. Hennon, C.A. Harrington, J.R. Popkin, J. Krapek, M.S. Lamb, L.E. Oakes, S. Saunders, S. Zeglen. 2017. Emerging climate-driven disturbance processes: Widespread mortality associated with snow-to-rain transitions across 10º of latitude and half the range of a climate-threatened conifer. Global Change Biology 23: 2903-2914.
46. Stewart, J.A.E., J.D. Perrine, L.B. Nichols, J.H. Thorne, C.I. Millar, K.E. Goehring, C.P. Massing, and D.H.

Wright. 2015. Revisiting the past to foretell the future: Summer temperature and habitat area predict pika extirpations in California. Journal of Biogeography 42: 880-890.

47. Coates, P.S., M.A. Ricca, B.G. Prochazka, M.L. Brooks, K.E. Doherty, T. Kroger, E.J. Blomberg, C.A. Hagen, and M.L. Casazza. 2016. Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems. Proceedings of the National Academy of Sciences of the USA 113: 12 745-12 750.
48. Boyte, S.P., B.K. Wylie, and D.J. Major. 2016. Cheatgrass percent cover change: Comparing recent estimates to climate change-driven predictions in the northern Great Basin. Rangeland Ecology and Management 69: 265-279.
49. Wu, J.X., C.B. Wilsey, L. Taylor, and G.W. Schuurman. 2018. Projected avifaunal responses to climate change across the U.S. National Park System. PLoS ONE 13 e0190557 doi:10.1371/journal.pone.0190557.
50. Pike, D.A. and J.C. Stiner. 2007. Sea turtle species vary in their susceptibility to tropical cyclones. Oecologia 153: 471-478.
51. Flower, H., M. Rains, and C. Fitz. 2017. Visioning the future: Scenarios modeling of the Florida coastal Everglades. Environmental Management 60: 989-1009.
52. Griggs, G., J. Árvai, D. Cayan, R. DeConto, J. Fox, H.A. Fricker, R.E. Kopp, C. Tebaldi, and E.A. Whiteman. 2017. Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust, Oakland, CA.
53. CMG Landscape Architecture. 2016. Crissy Field + Sea Level Rise-Up. CMG, San Francisco, CA.
54. Ayyub, B.M., H.G. Braileanu, and N. Qureshi. 2012. Prediction and impact of sea level rise on properties and infrastructure of Washington, DC. Risk Analysis 32: 1901-1918.
55. Murdukhayeva, A., P. August, M. Bradley, C. LaBash, and N. Shaw. 2013. Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. Journal of Coastal Research 29: 1-16.
56. Marzeion, B. and A. Levermann. 2014. Loss of cultural world heritage and currently inhabited places to sea-level rise. Environmental Research Letters 9: 034001. doi:10.1088/1748-9326/9/3/034001.
57. Kuffner, I.B., T.D. Hickey, and J.M. Morrison. 2013. Calcification rates of the massive coral Siderastrea siderea and crustose coralline algae along the Florida Keys (USA) outer-reef tract. Coral Reefs 32: 987-997.
58. Marshall, K.N., I.C. Kaplan, E.E. Hodgson, A. Hermann, D.S. Busch, P. McElhany, T.E. Essington, C.J. Harvey, and E.A. Fulton. 2017. Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections. Global Change Biology 23: 1525-1539.
59. Johnston, K.M., K.A. Freund, and O.J. Schmitz. 2012. Projected range shifting by montane mammals under climate change: implications for Cascadia's National Parks. Ecosphere 3(11): 97. doi:10.1890/ES12-00077.1.
60. Morelli, T.L. et al. 2016. Managing climate change refugia for climate adaptation. PLoS One 11: e0159909. doi:10.1371/journal.pone.0159909.
61. Briggs, M.A., J.W. Lane, C.D. Snyder, E.A. White, Z.C. Johnson, D.L. Nelms, and N.P. Hitt. 2018. Shallow bedrock limits groundwater seepage-based headwater climate refugia. Limnologica 68: 142-156.
62. van Mantgem, P.J., A.C. Caprio, N.L. Stephenson, and A.J. Das. 2016. Does prescribed fire promote

resistance to drought in low elevation forests of the Sierra Nevada, California, USA? Fire Ecology 12: 13-25.

63. Boisramé, G., S. Thompson, B. Collins, and S. Stephens. 2017. Managed wildfire effects on forest resilience and water in the Sierra Nevada. Ecosystems 20: 717-732.
64. Urban, M.C. 2015. Accelerating extinction risk from climate change. Science 348: 571-573.
65. United Nations Framework Convention on Climate Change (UNFCCC). 2015. Adoption of the Paris Agreement. Document FCCC/CP/2015/10/Add1, Decision 1/CP21. UNFCCC, Bonn, Germany.
66. Van Pelt, R., S.C. Sillett, W.A. Kruse, J.A. Freund, NS R.D. Kramer. 2016. Emergent crowns and light-use complementarity lead to global maximum biomass and leaf area in Sequoia sempervirens forests. Forest Ecology and Management 375: 279-308.
67. Gonzalez, P., J.J. Battles, B.M. Collins, T. Robards, and D.S. Saah. 2015. Aboveground live carbon stock changes of California wildland ecosystems, 2001-2010. Forest Ecology and Management 348: 68-77.
68. Intergovernmental Panel on Climate Change. 2018. Global warming of 1.5°C. [Masson-Delmotte, V. et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland.
69. U.S. Environmental Protection Agency (US EPA). 2018. Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016. US EPA, Washington, DC.
70. U.S. Climate Alliance. 2018. Annual Report. U.S. Climate Alliance, Washington, DC.
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