

Climate Change Trends and Ecological Vulnerabilities at Mount Rainier National Park

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Introduction

Greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities have increased temperatures around the world and changed other aspects of climate (IPCC 2007a). Published field research shows that climate change is also altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2007b). To assist Mount Rainier National Park (NP) in efforts to integrate climate change into its foundation document and resource management planning, this report presents results of spatial analyses of historical and projected climate change and a summary of published scientific findings for the Mount Rainier area on climate change impacts and vulnerabilities. The report only uses information from peer-reviewed scientific publications.

Historical Climate Changes and Physical Changes

From 1901 to 2002, average annual temperature increased across the United States (U.S.) (Figure 1) and showed a statistically significant increase in the 50 km x 50 km (30 mile x 30 mile) square that includes Mount Rainier NP (Figure 2, Table 1). Precipitation also increased across the U.S. (Figure 3) and in the 50 km x 50 km square that includes Mount Rainier NP, but the trend in the area of the park was not statistically significant (Figure 4). The weather station at Longmire, in the park, did not show statistically significant changes for temperature or precipitation (Table 1, Figure 1, Figure 3).

Analyses of data from weather stations and snow courses across the western United States, including Mount Rainier NP, have detected statistically significant changes in the 20th century and attributed these to climate change. The changes include increased winter temperatures (Barnett et al. 2008; Bonfils et al. 2008), decreased snowpack (Barnett et al. 2008; Pierce et al. 2008), decreased ratio of snow to rain (Pierce et al. 2008), and earlier spring streamflow (Barnett et al. 2008) from 1950 to 1999.

An array of small weather sensors set out in 2009-2010 in Mount Rainier NP indicates that air

and soil temperatures and snow disappearance date can vary in locations just a few meters apart due to differences in tree canopy, topography, and other site-specific characteristics (Ford et al. 2013). This highlights the high spatial variability of climate in the park.

Analyses of snow course and tree ring data from sites across the Rocky Mountains have detected melting of snowpack and glaciers in the 20th century greater than any time since 1200 AD and attributed the melting to climate change (Pederson et al. 2011). Although this research did not include the Cascade Range, measurements of Mount Rainier glaciers have shown substantial decreases in recent decades consistent with, but not formally attributed to, human climate change. Comparison of a digital elevation models derived from 1970 aerial photos and 2007-2008 light detection and ranging (Lidar) data showed that Mount Rainier lost 14% of its glacial ice and perennial snow during the 37-38 year period (Sisson et al. 2011). All of the Mount Rainier glaciers, except the Emmons and Winthrop glaciers, thinned and retreated in their terminal regions. Thinning of south flank glaciers may reflect melting of high snowfall due to the Pacific Decadal Oscillation, rather than human climate change. Reconstruction of 1850-1979 climate at Longmire and comparison with glacier moraines indicates that the steady-state equilibrium-line altitude has raised 160 m since the maximum Neoglacial advance (Burbank 1982).

Historical Ecological Changes

Field measurements from Mount Rainier NP have contributed to the detection of statistically significant 20th century ecological changes and analysis of climate and other factors have attributed the ecological changes to climate change. Tracking of trees in permanent old-growth forest plots across the western U.S. found a statistically significant increase of tree mortality between 1955 and 1994 (van Mantgem et al. 2009). Analyses of fire, mortality of small trees, forest fragmentation, air pollution, and climate attribute the mortality to warming due to climate change. In the Pacific Northwest, tree mortality doubled between the mean census interval midpoint years of 1982 and 2000. Although mortality increased in the Mount Rainier plots, species composition did not change (Acker et al. 2006). Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor controlling burned area, even during periods of active fire suppression (Littell et al. 2009). Climate change has also caused bark beetle outbreaks leading to the most extensive tree mortality across western North America in the last 125 years (Raffa et al. 2008). Outbreaks of mountain pine

beetles have occurred in the Cascade Range, but mortality has not been as extensive as in the Rocky Mountains.

Other research has detected 20th century ecological impacts that are consistent with, but not statistically attributed to, human climate change. In mid-elevation conifer forests of the western U.S., including Mount Rainier, increases in spring and summer temperatures, earlier snowmelt, and longer summers increased fire frequency 400% and burned area 650% from 1970 to 2003 (Westerling et al. 2006).

At Paradise Valley in the park, subalpine fir (*Abies lasiocarpa*) forest has been shifting into formerly open alpine meadows, with a pulse of tree establishment between 1923 and 1944 (Franklin et al. 1971). The absence of fire and grazing at that location and glacial recession at the time of the tree establishment suggest a change consistent with climate change. Tree establishment in alpine meadows at Paradise Valley continued until at least 1993 (Rochefort and Peterson 1996). West-side sites have shown a shift of subalpine forest into meadows, though drier east-side sites have not. These shifts of subalpine forest into alpine meadows seem to be occurring at numerous sites in the western U.S. (Rochefort et al. 1994).

Analyses of tree cores from sites in the park and climate data show that climate controls the upper elevation limit of Pacific silver fir (*Abies amabilis*), Alaska cedar (*Callitropsis nootkatensis*), and mountain hemlock (*Tsuga mertensiana*) (Ettinger et al. 2011). Field measurements indicate that climate, competition, and tree life stages all affect potential range shifts (Ettinger and HilleRisLambers 2013).

Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007a). The three main IPCC greenhouse gas emissions scenarios are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (Le Quéré et al. 2013, Raupach et al. 2007).

For the three main IPCC emissions scenarios, projected 21st century mean annual temperature in the Mount Rainier area could increase four to six times the 20th century increase (Table 1).

The average of ensembles of general circulation models (GCMs) of the atmosphere project increased precipitation for the Mount Rainier area under all three IPCC emissions scenarios, but with wide uncertainties (Table 1). For emissions scenario A2, 12 out of 18 GCMs project increases in precipitation (Figure 5).

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Modeling under emissions scenario A2 projects 35 to 45 fewer days with a minimum temperature < 0°C (32°F.) and six to 12 more consecutive days each year with precipitation < 3 mm (one-tenth of an inch) between the periods 1980-2000 and 2041-2070 (Kunkel et al. 2013).

Potential Future Vulnerabilities

If we do not reduce greenhouse gas emissions, continued warming may increase glacial melting, increase deposition of soil, gravel, and rocks and the risk of debris flows and flooding (Lancaster et al. 2012). Projections of wildfire under climate change indicate widespread increases in fire frequency around the world, including western Washington (Moritz et al. 2012).

Modeling of the potential ranges of eight mammal species across western Washington (Johnston et al. 2012) shows potential reductions of range for American marten (*Martes americana*), American pika (*Ochotona princeps*), Canada lynx (*Lynx canadensis*), hoary marmot (*Marmota caligata*), mountain goat (*Oreamnos americanus*), and wolverine (*Gulo gulo*), increases of range for gray squirrel (*Sciurus griseus*), and inconclusive results for elk (*Cervus canadensis*). Models results indicate that Mount Rainier NP may act as a refugium because of its high elevation.

Dependence of bird species ranges on elevation in the park (Siegel et al. 2012) suggests vulnerability to elevation shifts under climate change. Changes in forest habitats and other potential impacts of climate change suggest the vulnerability to reductions or shifts in habitat of several wildlife species, including the northern red-legged frog (*Rana aurora*), marbled murrelet (*Brachyramphus marmoratus*), northern spotted owl (*Strix occidentalis caurina*), American pika (*Ochotona princeps*), Cascade red fox (*Vulpes vulpes*), and hoary marmot (*Marmota caligata*) (Raymond et al. 2013).

Because Mount Rainier already experiences high ground-level ozone concentrations from Seattle-area emissions (Brace and Peterson 1998, Barna et al. 2000) and because increased temperature can increase ground-level ozone, climate change could increase vulnerability of the park to this pollutant.

Table 1. Historical and projected climate trends for the area that includes Mount Rainier NP (Mitchell and Jones 2005, IPCC 2007a, Gonzalez et al. 2010) and the weather station at Longmire, in the park (data National Oceanic and Atmospheric Administration). Historical area climate and projections for IPCC emissions scenarios B1 and A1B calculated at 50 km spatial resolution (Gonzalez et al. 2010). Climate under emissions scenario A2 calculated at 4 km spatial resolution (data from Conservation International, method of Tabor and Williams (2010)).

	mean SD/SE		mean SD/SE	
Historical				
<i>Area that includes the park (1901-2002)</i>				
temperature annual average ± SD	11.2	0.6 °C	52	1 °F.
temperature linear trend ± SE	0.6	0.2 °C/century	1	0.3 °F./cent.
precipitation annual average ± SD	1050	170 mm/y	41	7 in./year
precipitation linear trend ± SE	6	5 %/century	6	5 %/century
 <i>Longmire, Mount Rainier NP</i>				
temperature average (1915-2011) ± SD	7.1	0.8 °C	45	1.4 °F.
temperature linear trend ± SE	0.1	0.3 °C/century	0.2	0.5 °F./cent.
precipitation average (1914-2012) ± SD	2100	370 mm/y	82	14 in./year
precipitation linear trend ± SE	3	7 %/century	3	7 %/century
 Projected (1990-2100) ± SD				
IPCC B1 scenario (lower emissions)				
temperature annual average trend	2.3	0.8 °C/century	4.2	1.4 °F./cent.
precipitation annual average trend	5	4 %/century		4 %/century
 IPCC A1B scenario (medium emissions)				
temperature annual average trend	3.0	0.8 °C/century	5.3	1.4 °F./cent.
precipitation annual average trend	6	4 %/century		4 %/century
 IPCC A2 scenario (higher emissions)				
temperature annual average trend	3.5	0.8 °C/century	6.3	1.4 °F./cent.
precipitation annual average trend	3	4 %/century	3	4 %/century

SD = standard deviation; SE = standard error

Figure 1.

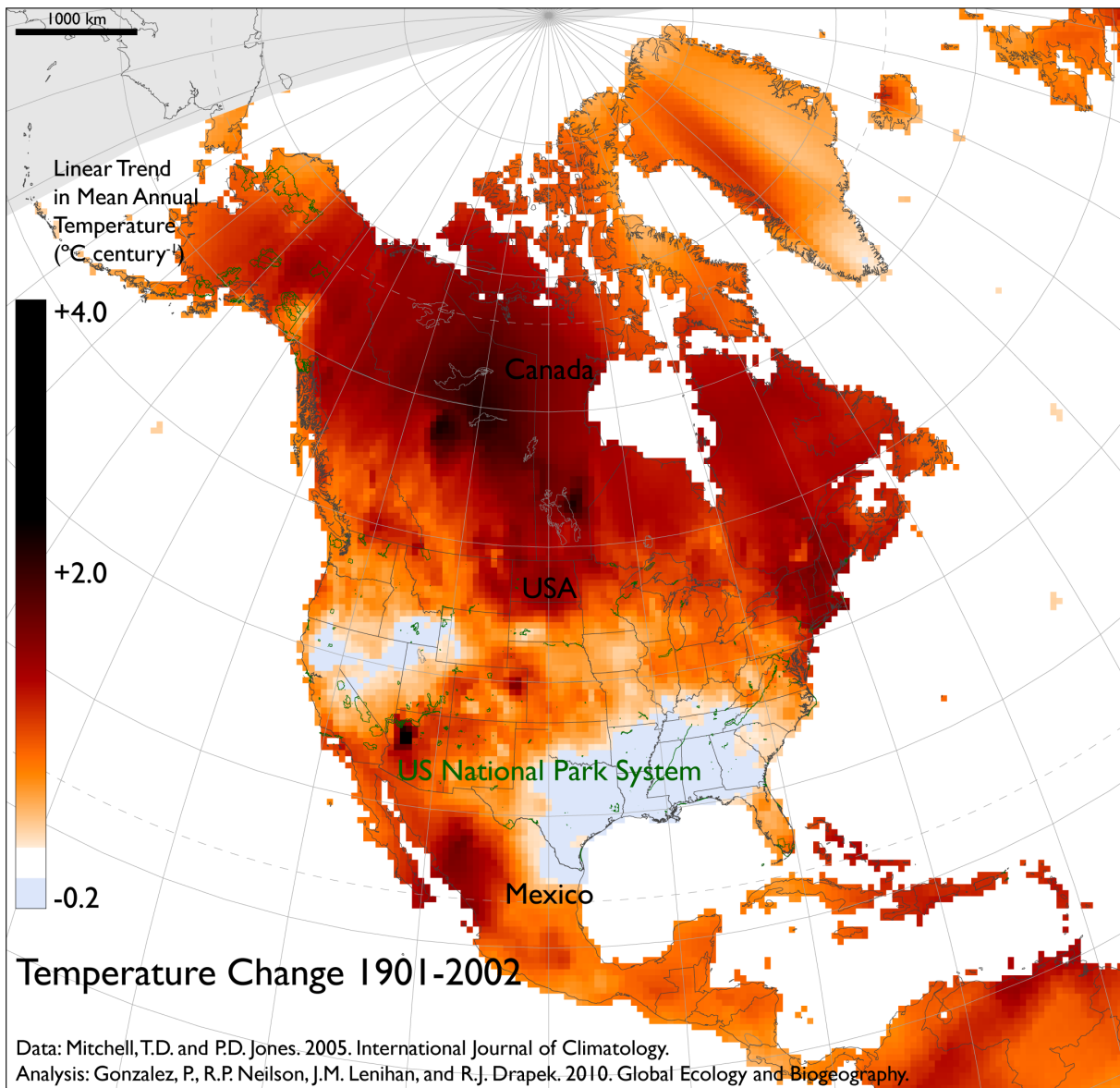


Figure 2.

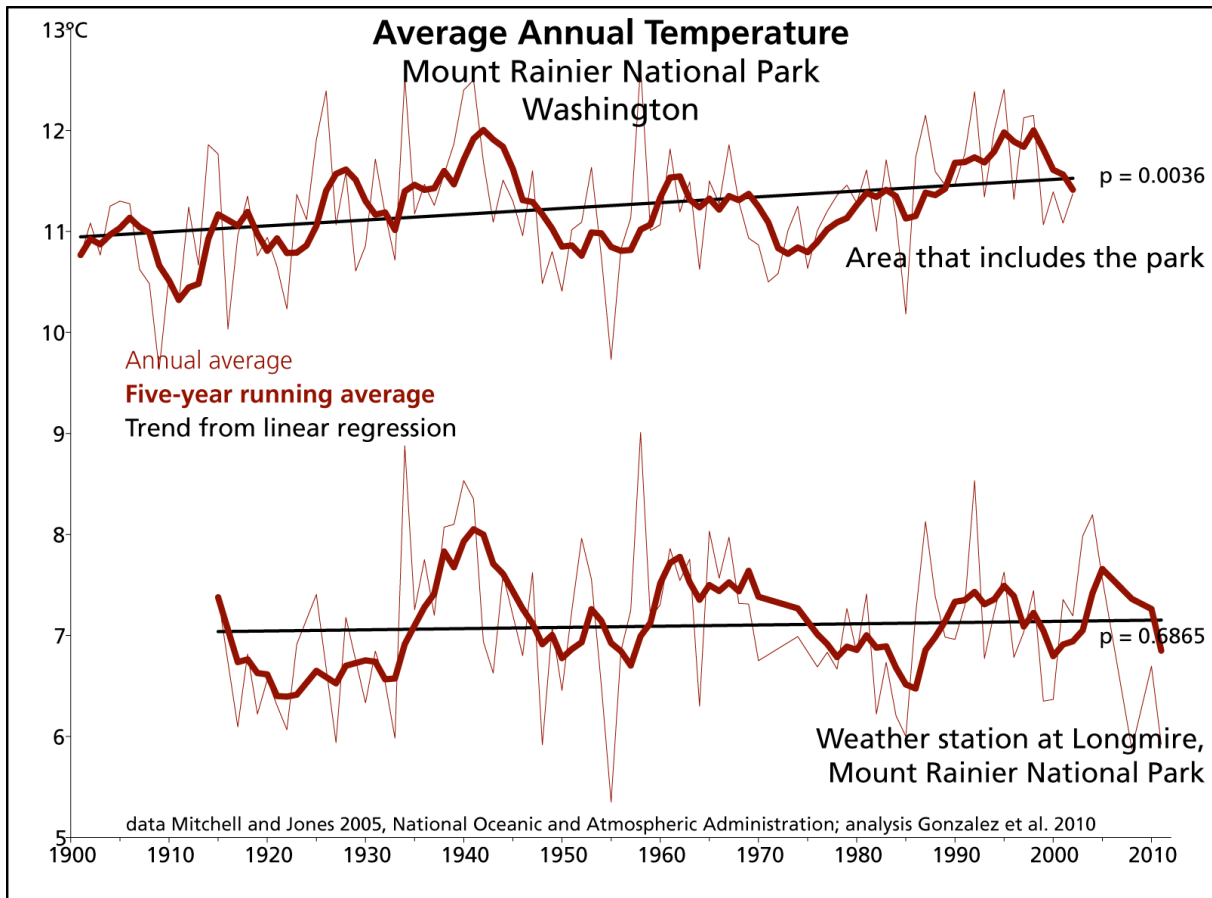


Figure 3.

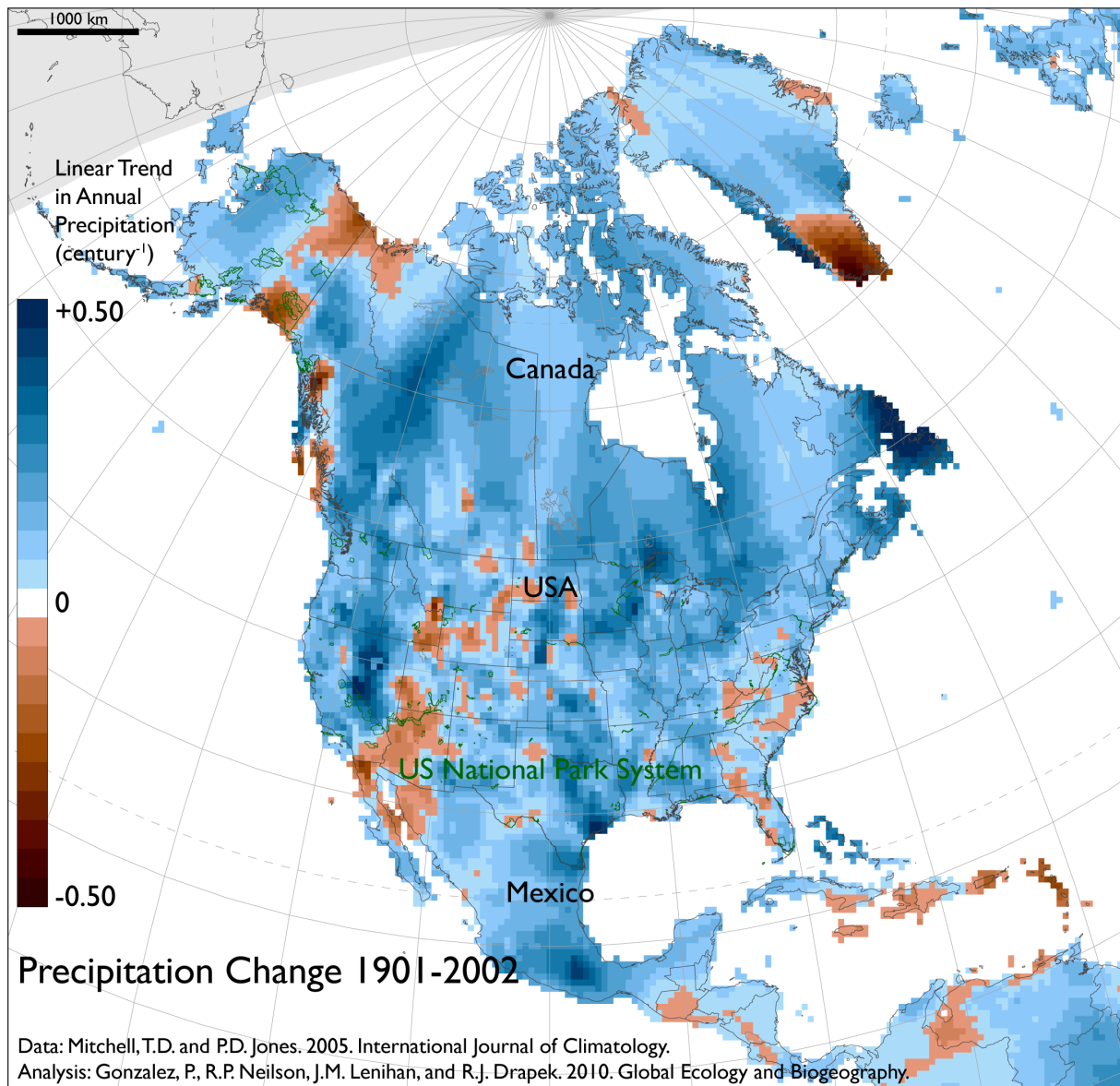


Figure 4.

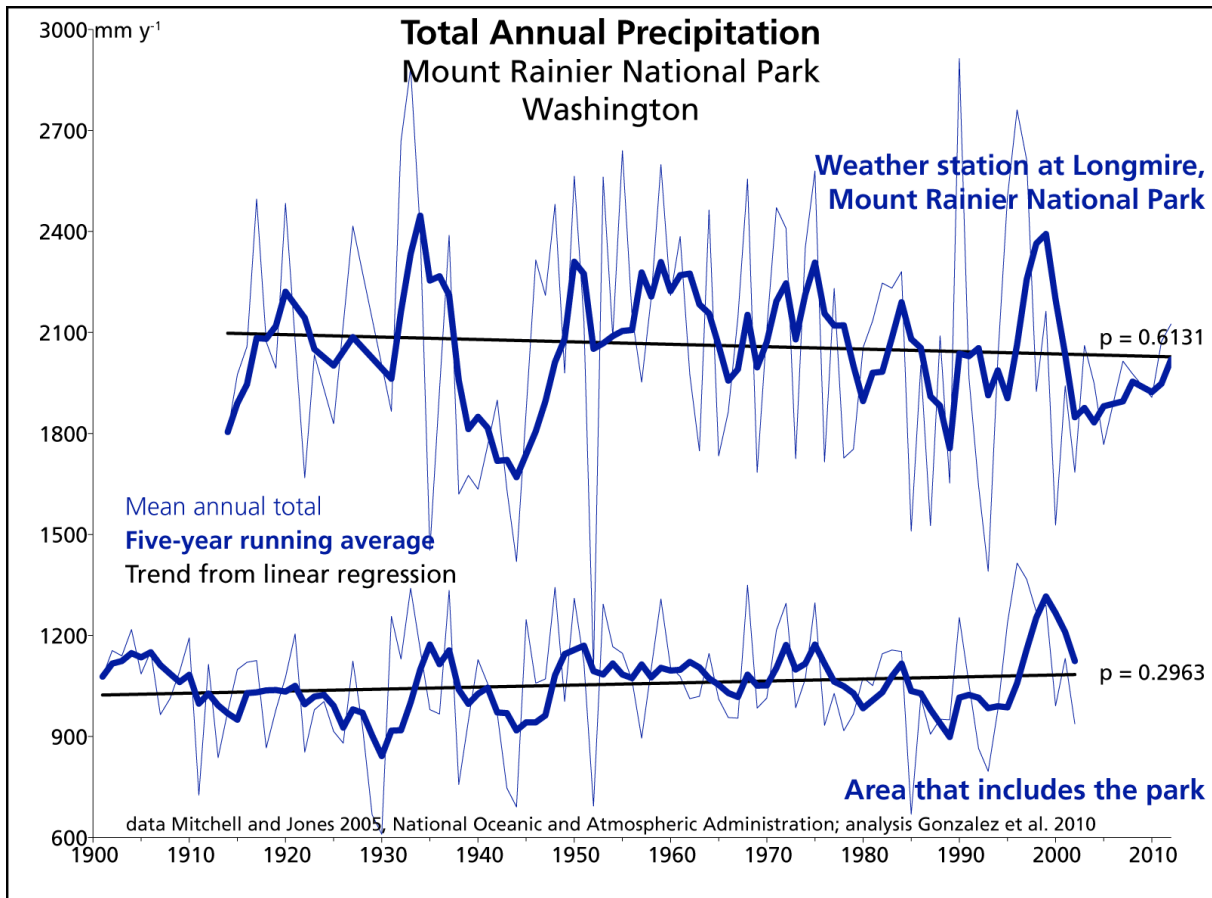
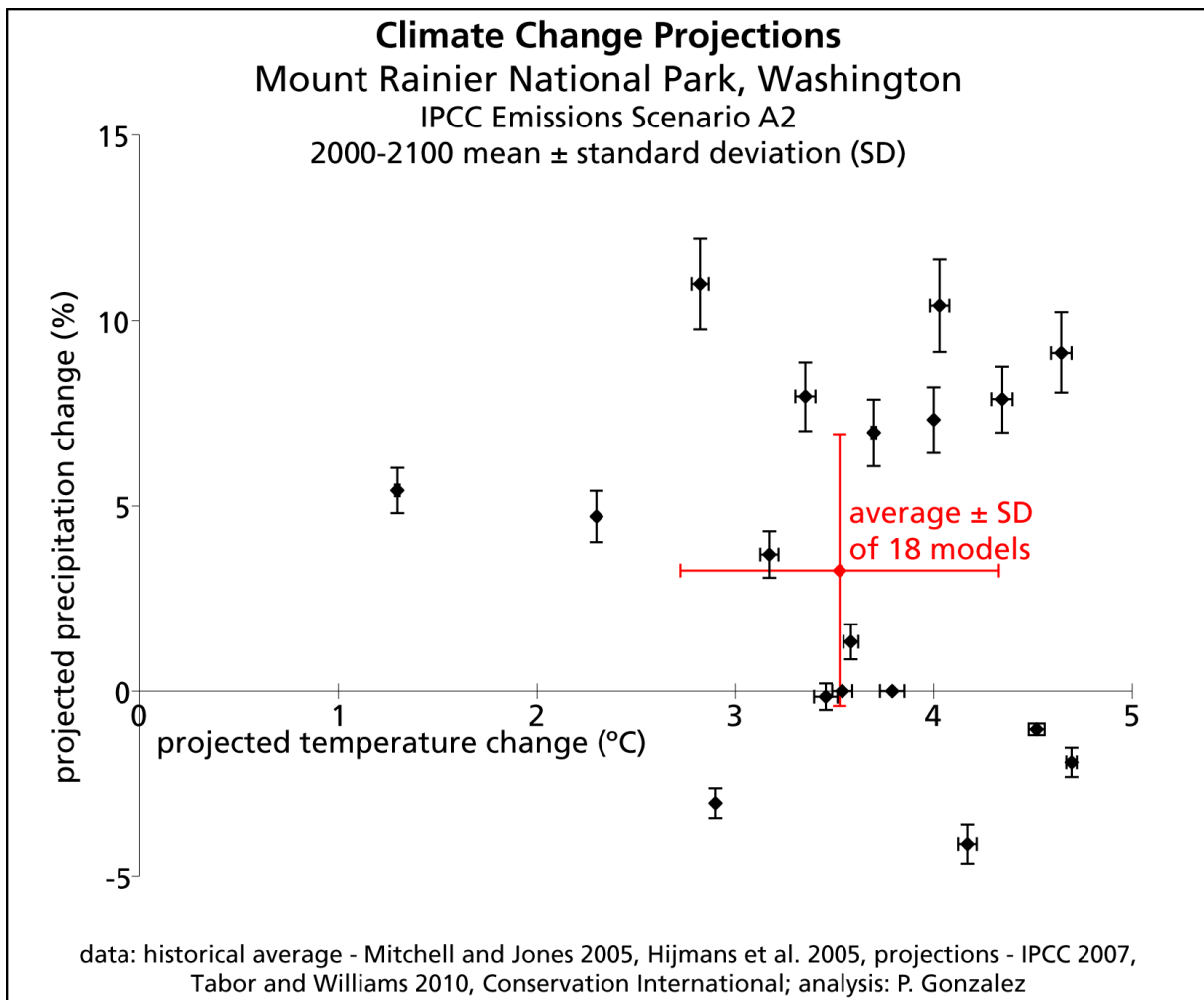


Figure 5.



References

- Acker, S.A., J.F. Franklin, S.E. Greene, T.B. Thomas, R. Van Pelt, and K.J. Bible. 2006. Two decades of stability and change in old-growth forest at Mount Rainier National Park. *Northwest Science* 80: 65-72.
- Barna, M., B. Lamb, S. O'Neill, H. Westberg, C. Figueroa-Kaminsky, S. Otterson, C. Bowman, and J. DeMay. 2000. Modeling ozone formation and transport in the Cascadia region of the Pacific Northwest. *Journal of Applied Meteorology* 39: 349-366.
- Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. *Science* 319: 1080-1083.
- Bonfils, C., B.D. Santer, D.W. Pierce, H.G. Hidalgo, G. Bala, T. Das, T.P. Barnett, D.R. Cayan, C. Doutriaux, A.W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous western United States. *Journal of Climate* 21: 6404-6424.
- Brace, S. and D.L. Peterson. 1998. Spatial patterns of tropospheric ozone in the mount rainier region of the cascade mountains, USA. *Atmospheric Environment* 32: 3629-3637.
- Burbank, D.W. 1982. Correlations of climate, mass balances, and glacial fluctuations at Mount Rainer, Washington, U.S.A., since 1850. *Arctic and Alpine Research* 14: 137-148.
- Ettinger, A. K., K. R. Ford, and J. HilleRisLambers. 2011. Climate determines upper, but not lower, altitudinal range limits of Pacific Northwest conifers. *Ecology* 92: 1323-1331.
- Ettinger, A.K. and J. HilleRisLambers. 2013. Climate isn't everything: Competitive interactions and variation by life stage will also affect range shifts in a warming world. *American Journal of Botany* 100: 1344-1355.
- Ford, K.R., A.K. Ettinger, J.D. Lundquist, M.S. Raleigh, and J. HilleRisLambers. 2013. Spatial heterogeneity in ecologically important climate variables at coarse and fine scales in a high-snow mountain landscape. *PLoS ONE* 8(6): e65008. doi:10.1371/journal.pone.0065008.
- Franklin, J.F., W.H. Moir, G.W. Douglas, and C. Wiberg. 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. *Arctic and Alpine Research* 3: 215-224.
- 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.

- Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.
- Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2007b. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, UK.
- 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. <http://dx.doi.org/10.1890/ES12-00077.1>.
- Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 6. Climate of the Northwest U.S.* National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-6, Washington, DC.
- Lancaster, S.T., A.W. Nolin, E.A. Copeland, and G.E. Grant. 2012. Periglacial debris-flow initiation and susceptibility and glacier recession from imagery, airborne LiDAR, and ground-based mapping. *Geosphere* 8: 417-430.
- Le Quéré, C., R.J. Andres, T. Boden, T. Conway, R.A. Houghton, J.I. House, G. Marland, G.P. Peters, G.R. van der Werf, A. Ahlström, R.M. Andrew, L. Bopp, J.G. Canadell, P. Ciais, S.C. Doney, C. Enright, P. Friedlingstein, C. Huntingford, A.K. Jain, C. Jourdain, E. Kato, R.F. Keeling, K. Klein Goldewijk, S. Levis, P. Levy, M. Lomas, B. Poulter, M.R. Raupach, J. Schwinger, S. Sitch, B.D. Stocker, N. Viovy, S. Zaehle, and N. Zeng. 2013. The global carbon budget 1959–2011. *Earth System Science Data* 5: 165-185.
- 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.
- Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25: 693-712.
- Moritz, M.A., M.A. Parisien, E. Batllori, M.A. Krawchuk, J. Van Dorn, D.J. Ganz, and K. Hayhoe. 2012. Climate change and disruptions to global fire activity. *Ecosphere* 3: art49. doi:10.1890/ES11-00345.1.
- 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.

Pierce, D.W., T.P., Barnett, H.G. Hidalgo, T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D.

Dettinger, D.R. Cayan, A. Mirin, A.W. Wood, and T. Nozawa. 2008. Attribution of declining western U.S. snowpack to human effects. *Journal of Climate* 21: 6425-6444.

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.

Raupach, M.R., G. Marland, P. Ciais, C. Le Quéré, J.G. Canadell, G. Klepper, and C.B. Field.

2007. Global and regional drivers of accelerating CO₂ emissions. *Proceedings of the National Academy of Sciences of the USA* 104:10 288-10 293.

Raymond, C.L., D.L. Peterson, R.M. Rochefort. 2013. The North Cascadia adaptation

partnership: A science-management collaboration for responding to climate change. *Sustainability* 5: 136-159.

Rochefort, R.M. and D.L. Peterson. 1996. Temporal and spatial distribution of trees in subalpine

meadows of Mount Rainier National Park, Washington, U.S.A. *Arctic and Alpine Research* 28: 52-59.

Rochefort, R.M., R.L. Little, A. Woodward, and D.L. Peterson 1994. Changes in sub-alpine tree

distribution in western North America: A review of climatic and other causal factors. *The Holocene* 4: 89-100.

Siegel, R.B., R.L. Wilkerson, R.C. Kuntz, J.F. Saracco, and A.L. Holmgren. 2012. Elevation

ranges of birds at Mount Rainier National Park, North Cascades National Park complex, and Olympic National Park, Washington. *Northwestern Naturalist* 93: 23-39.

Sisson, T.W., J.E. Robinson, and D.D. Swinney. 2011. Whole-edifice ice volume change A.D.

1970 to 2007/2008 at Mount Rainier, Washington, based on LiDAR surveying. *Geology* 39: 639-642.

Tabor, K. and J.W. Williams. 2010. Globally downscaled climate projections for assessing the

conservation impacts of climate change. *Ecological Applications* 20: 554-565.

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.

Westerling, A., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier Spring

increase western U.S. forest wildfire activity. *Science* 313: 940-943.