Climate Change Vulnerability

Climate change has the potential to alter freshwater habitat in many complex ways that are not yet fully understood. These changes are expected to greatly affect the health and distribution of fish species, particularly those adapted to cold water (U.S. Fish and Wildlife Service 2009; Williams, Haak, et al. 2009; Rieman, Isaak, et al. 2007; Mote et al. 2003). Because of this complexity, we chose an approach that was not species specific, but instead identified the vulnerability of each sub-basin to the effects of climate change that would most directly impact freshwater habitat: air temperature, flow regime, and wildfire.

Climate change is expected to alter air temperature and precipitation, not just in magnitude but also in spatial and temporal distribution. In the Pacific Northwest, these effects will generally manifest as warmer year-round temperatures, with wetter winters and drier summers (Littell et al. 2009). Regional winter temperatures may increase 0.2^{o} to 0.6^{o} C per decade, and are expected to cause more precipitation falling as rain rather than snow and earlier snowmelt (Nolin and Daly 2006; Mote et al. 2003). A primary result of these trends will be a reduction in snowpack (Mote et al. 2003). In a region that relies on winter snowpack and its run-off to store water from winter-concentrated precipitation, this would result in earlier high flows, summer droughts, and warmer water (Nolin and Daly 2006; Mote et al. 2003). Changes in the magnitude and timing of flows, warmer stream temperatures, and increased frequency and intensity of other disturbances are the climate change impacts most likely to have the greatest effect on native trout and other fish populations in the western United States (Williams, Haak, et al. 2009).

Additionally, changes in wildfire extent and severity are projected to affect freshwater habitat. Forest wildfire frequency and total area burned are closely associated with timing of snowmelt; as snowmelt occurs earlier, the length of the fire season and number of fires increase (Haak, Williams, Isaak, Todd, Muhlfeld, Kershner, Gresswell, Hostetler, and Neville 2010a; Williams, Haak, et al. 2009; Westerling et al. 2006). In the short-term, wildfire may create lethal high temperatures for coldwater fishes in small streams (Isaak et al. 2010), while more chronic impacts would result from the effects of altered riparian vegetation, including loss of shade, increased runoff, and post-fire landslides and debris flows (Isaak et al. 2010).

Because of the uncertainty and variability of this data, we created indices of each of these three components to rank relative sub-basin vulnerability to increase in air temperature, flow regime change, and wildfire change. Each is ranked on relative scale from *n* to 100, with 100 representing the highest vulnerability value present in each metric, and *n* the lowest[1]. In this way we can analyze these disparate data inputs together to create a final measure of vulnerability to climate change. The coarse resolution of the input datasets dictated the scale of our analysis to the 4th, rather than 5th-level HUC. The index score for each 4th-field HUC was assigned to its subset of 5th-field watersheds.

Vulnerability to Air Temperature Change

The effect of climate change on water temperature is not necessarily a direct one (N. J. Mantua, Tohver, and Hamlet 2009). Vegetation cover, temporal distribution of increased air temperature, and water source are just a few of the factors affecting stream temperature response to increased air temperature (Arismendi 2011; Diabat 2011; Mayer 2011). However, because there is little consensus and less data

[1] For example, if we measured three sub-basins to have temperature change values of 4.8, 3.1, and 1.5, we would divide all the values by 0.048 to create an index where the sub-basins were ranked as 100, 65, and 31, respectively. It is important to note that the sub-basin ranked 65 is not necessarily twice as vulnerable as that ranked 31. It is more useful to look at the distribution of vulnerability values both quantitatively and spatially.

available to model this complexity, particularly at this scale, we developed an index of vulnerability to air temperature change. For this purpose we assumed that sub-basins with the greatest air temperature increase would be most vulnerable due to their exposure. There is also some indication that streams with a high base flow index (BFI), the proportion of total flow fed by groundwater, may be more resistant to increasing air temperatures due to larger flow volumes during low flow periods and older, groundwater influx (Isaak 2011; Mayer and Naman 2011; Shively 2011). We therefore moderated the change in air temperature with BFI at the sub-basin scale.

We analyzed summer high air temperature, which is likely to be an important “pressure point” for fish in the Pacific Northwest (N. Mantua, Tohver, and Hamlet 2010). We focused on this seasonal component to target low-flow maximum water temperatures during the juvenile rearing period for most fish species and the time of year when increasing temperature as a result of climate change would be the most pronounced (Shively 2011). For each sub-basin, we calculated the change in monthly-average maximum daily summer air temperature between A1B warming scenario projections for 2099 and historic values using 6100-meter raster spatial data[2] (Figure 1) (Climate Impacts Group 2009a). Because the air temperature data did not cover our entire focal area and the range of temperature change was so limited (4.9 – 5.3 ^{o}C), we averaged the surrounding sub-basin values to each missing sub-basin in the Oregon portion of the Klamath River Basin and the Idaho portion of the Bear River Basin (Figure 2).

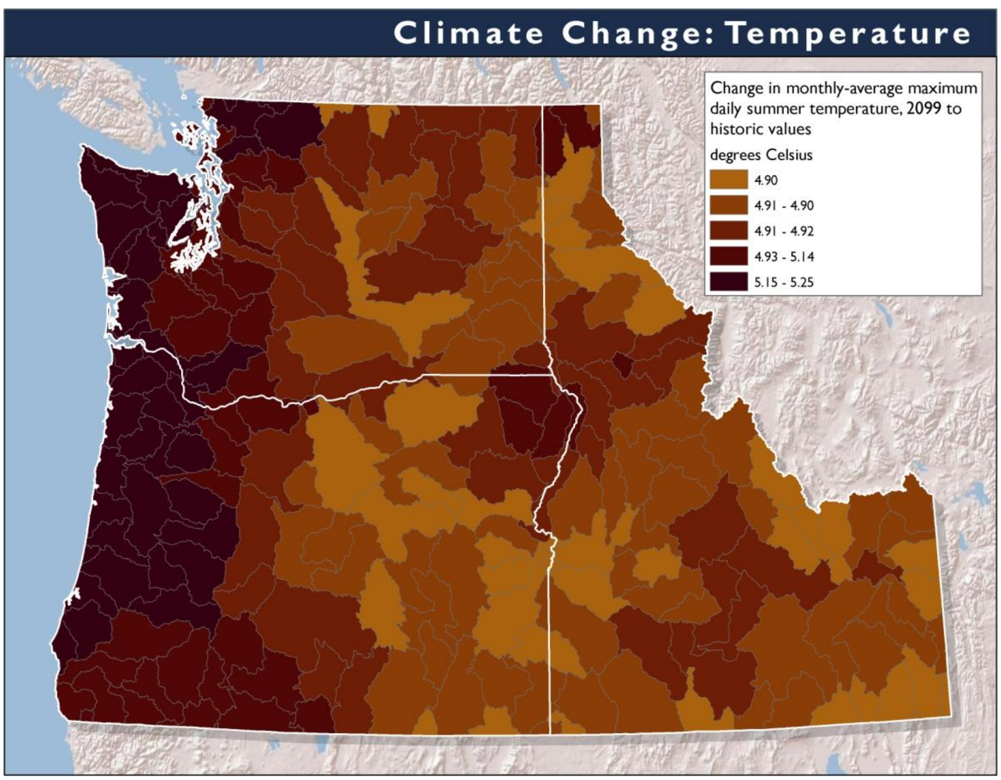

Figure 1. Change in monthly average maximum daily summer air temperature, 2099 to historic values, shown for the entire Pacific Northwest.

We then moderated this change in temperature with BFI raster data (Wolock 2003) by transforming mean sub-basin BFI (Figure 3) to a relative scale of 0.1 (highest mean BFI) to 1 (lowest mean BFI) and

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[2] For more information on all input datasets, please see the bibliography below, or the data dictionary available at http://aquatics-blm.labs.ecotrust.org/news/about/.

then multiplying mean sub-basin change in temperature by this relative modifier. We then scaled the resulting values from n - 100 to achieve a relative index of sub-basin vulnerability to air temperature (Figure 4).

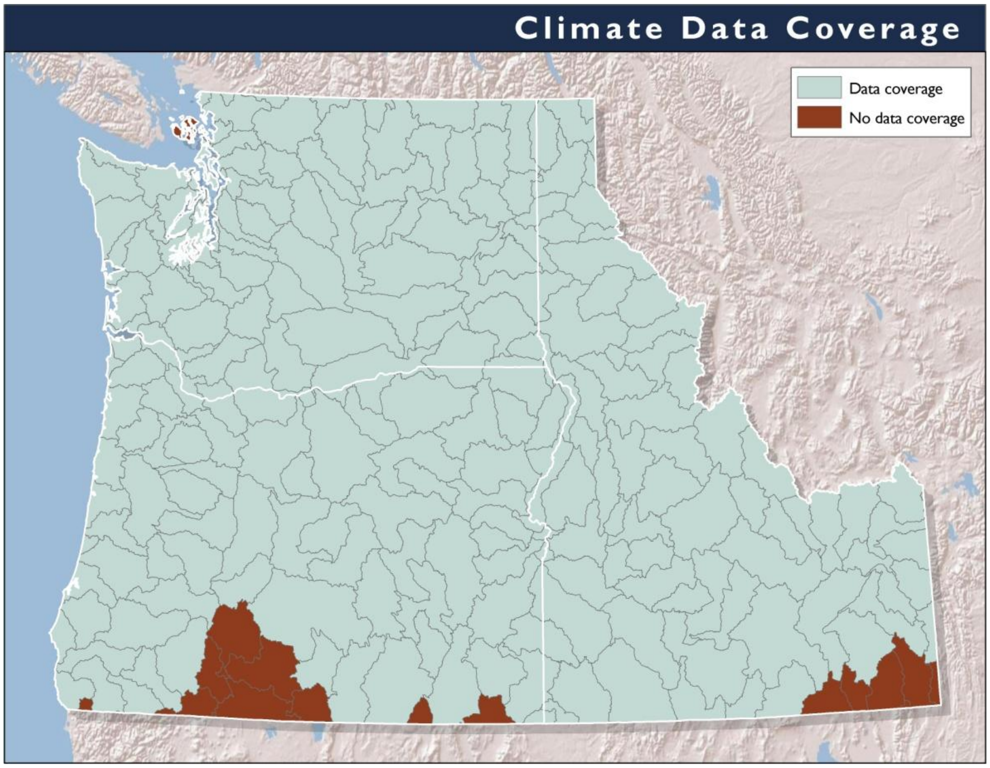

Figure 2. Climate Impacts Group climate data coverage across the Pacific Northwest.

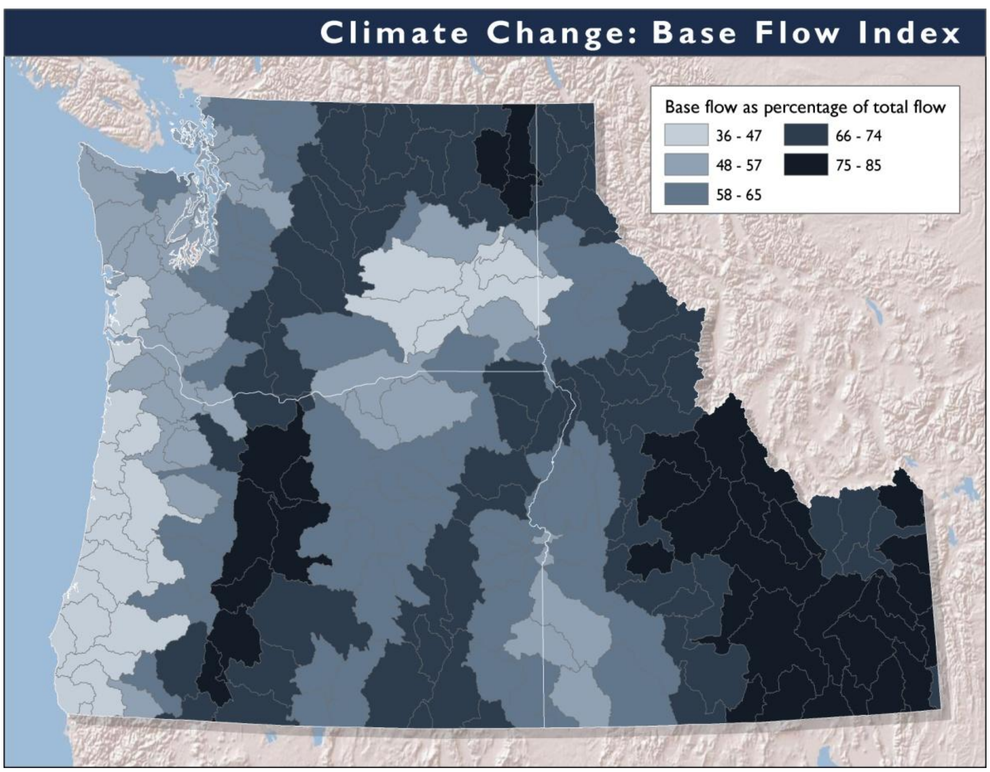

Figure 3. Sub-basin average base flow index across the Pacific Northwest.

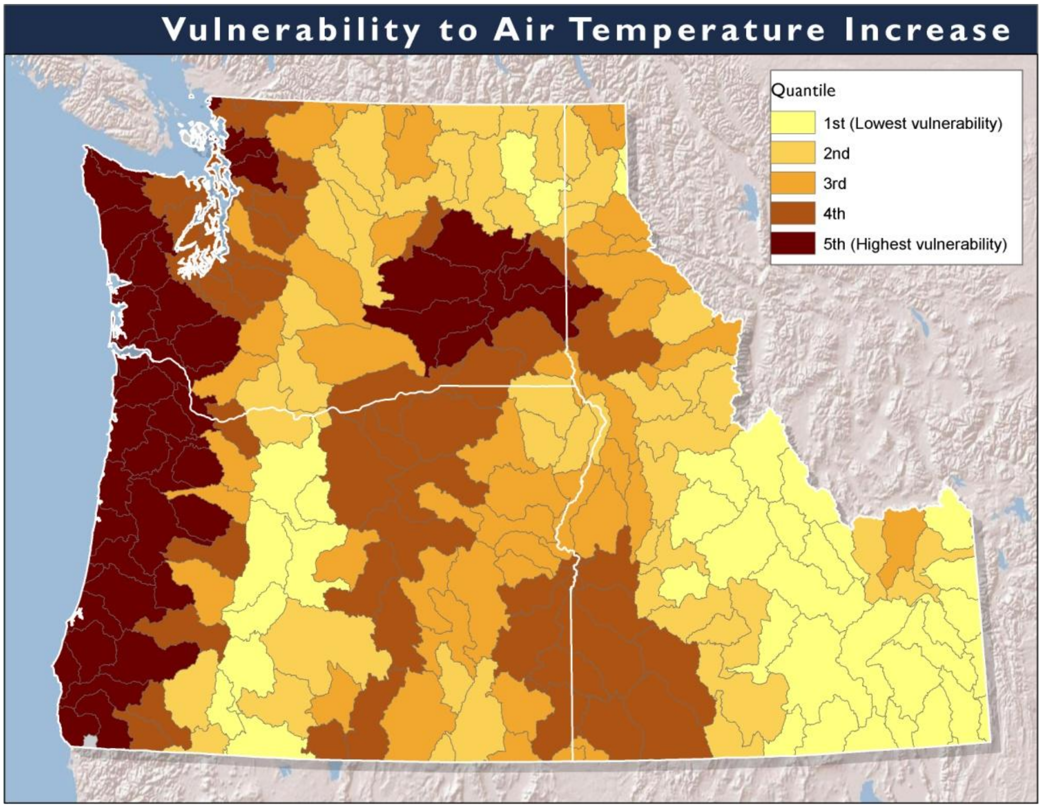

Figure 4. Vulnerability to air temperature increase across the Pacific Northwest

Vulnerability to Flow Regime Change

We classified historic and future (2080) sub-basin runoff as snowmelt, rainfall, or transient (a mix of snow and rain) following the approach in Mantua et al. (2010; 2009) and with further clarification by Mayer and Norheim (2011). Using 6100-meter raster spatial data of maximum snow water equivalent (SWE)(Climate Impacts Group 2009b) and October-March precipitation (Climate Impacts Group 2009c), we summed SWE and precipitation values for each sub-basin, and then calculated the ratio of the former to the latter for historic and 2080 conditions. Ratio classification ranges are listed in Table 1. We then identified those sub-basins where the flow regime would shift from one classification to another (Figure 5). Of 221 sub-basins, 45 (20%) are projected to change from snowmelt dominant to transient and 91 (41%) from transient to rain dominant. No sub-basins are projected to change from snowmelt to rain dominant, and 68 (30%) sub-basins are projected to maintain their historic flow regime.

Table 1. Sub-basin classification

SWE:PCP	Sub-basin classification
< 0.1	Rainfall dominant
0.1 - 0.4	Transient
> 0.4	Snowmelt dominant

While our other metrics within this climate change component had quantitative values, change in flow regime is qualitative and categorical. In order to compare this with the other quantitative metrics, we mapped these categories – change and no change – to our *n* – 100 scale. Sub-basins that changed flow regime – either from snow to transient, or transient to rain – were scored 100. Those that did not change were scored 0 to indicate their low vulnerability to change. The 17 sub-basins for which the necessary climate data did not exist (Figure 2) were given a median score of 50 in order to reflect our uncertainty and reduce their potential influence on the final outcome while still including them in the analysis.

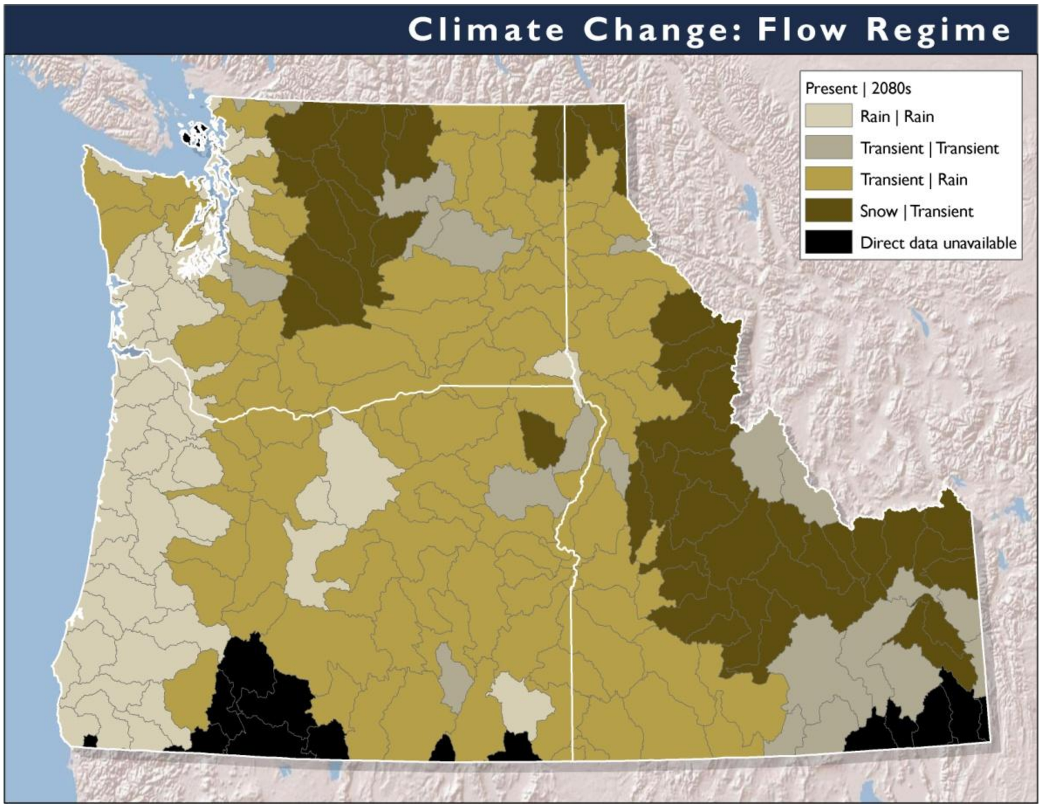

Figure 5. Projected change in flow regime, from 2080 to historic values.

Vulnerability to Increased Wildfire Risk

To identify sub-basin vulnerability to increased wildfire risk, we used an existing assessment published by the U.S. Geological Survey in cooperation with Trout Unlimited and the USDA Forest Service (Haak, Williams, Isaak, Todd, Muhlfeld, Kershner, Gresswell, Hostetler, and Neville 2010a). This work assumes that climate change in the western United States will increase the likelihood of wildfire when fuels and an ignition source are present. Areas where snowmelt occurs earlier are expected to have more fires in a longer fire season. This approach first classified areas outside an elevation range of 1,680 – 2,690 meters as low risk and removed them from the analysis, based on an approach by Westerling (2006). Within that elevation range, grassland and mesic shrublands were classified as low risk (score = 1), and all other fuel types were classified as high (score = 3). Urban areas, agricultural lands and barren ground were considered non-fuel categories and given a score of 0. These scores were provided in an 844-meter raster dataset (Haak, Williams, Isaak, Todd, Muhlfeld, Kershner, Gresswell, Hostetler, and Neville 2010b). We averaged these wildfire risk score values to the sub-basin, resulting in a range of values from 0 to 3 (Figure 6), and created an index by rescaling that range of risk from *n to* 100, to identify areas most vulnerable to an increase in wildfire risk due to climate change.

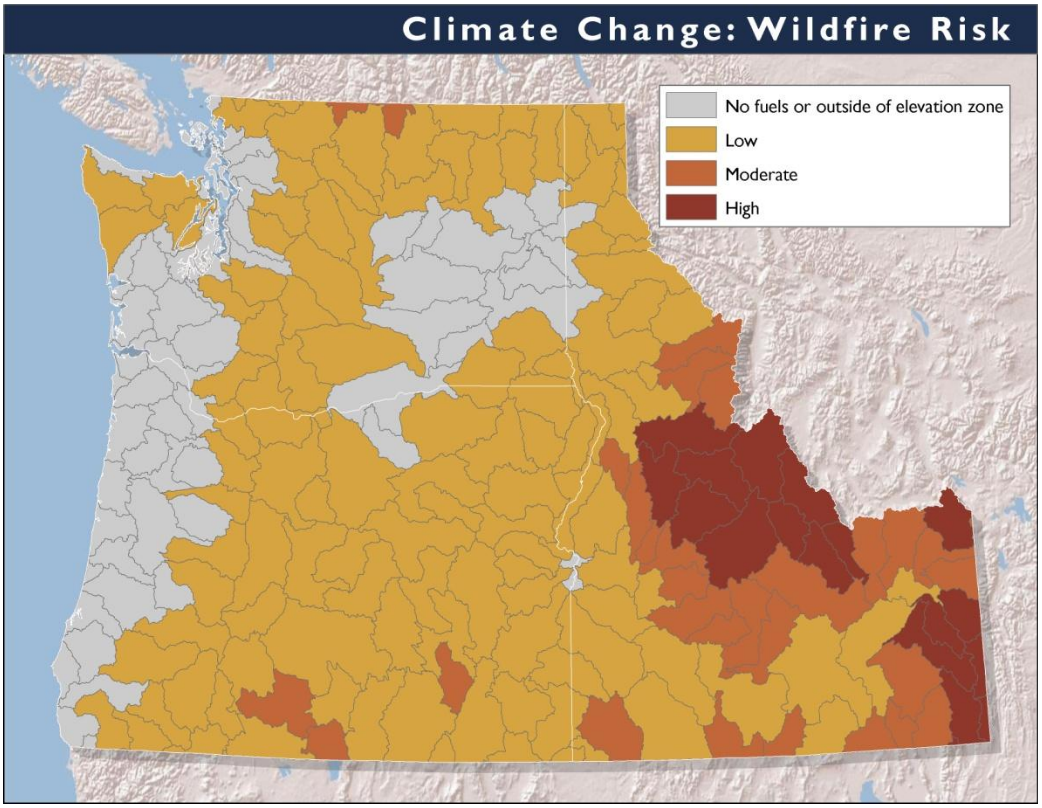

Figure 6. Wildfire risk due to climate change, as modeled by Haak et al. (2010a). For visualization purposes only, sub-basins with an averaged wildfire risk score of <1 are classified here as low, >1 and <2 as moderate, and >2 as high.

Climate Change Vulnerability Index

We added the unweighted sub-basin scores for air temperature, flow regime, and wildfire and re-indexed the totals on an *n* – 100 scale to create a comprehensive, relative ranking of sub-basins (Figure 7).

All sub-basins that rate low for vulnerability to climate change are projected to stay within their current flow regime classification. These sub-basins are either rain-dominated and expected to stay rain-dominated or are classified in the transient flow regime category and expected to stay in that flow regime class by 2080 (Figure 5). The Lower Crooked sub-basin (Deschutes River basin, Oregon) is an example of a sub-basin rated low for vulnerability to climate change overall with all three index scores for air temperature, flow regime, and wildfire rated low (Table 2). The Portneuf sub-basin (Upper Snake River basin, Idaho) is an example of a sub-basin that rates low for vulnerability to climate change overall, yet has a moderate wildfire vulnerability rating. The Puyallup (Puget Sound basin, Washington) and North Umpqua sub-basins (Southern Oregon Coastal Basin, Oregon) are two examples of sub-basins that rate low for vulnerability to climate change overall, yet have somewhat high air temperature vulnerability ratings.

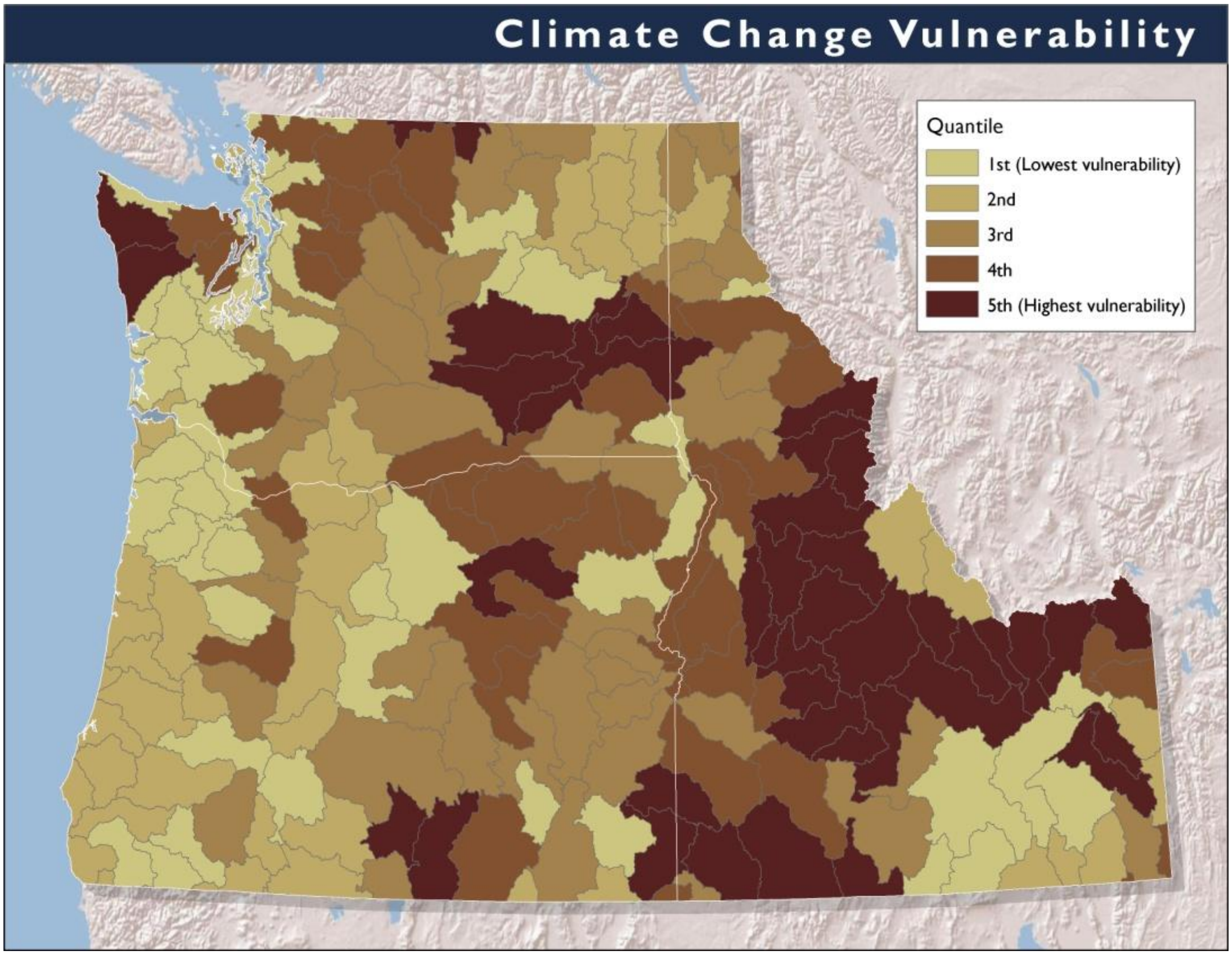

Figure 7. Sub-basin vulnerability to climate change in the Pacific Northwest.

All sub-basins that rate high for vulnerability to climate change have a change in projected flow regime from either snow-dominated to transient or transient to rain-dominated (Figure 5). The Upper Columbia-Priest Rapids sub-basin (Upper Columbia basin, Washington) is an example of a sub-basin that rates high for vulnerability to climate change overall, with a high air temperature rating and a low wildfire rating (Table 2). In contrast, the Upper Henrys and Blackfoot sub-basins (both in the Upper Snake basin, Idaho) also rate high for vulnerability to climate change overall, however, both rate low for temperature vulnerability and high for wildfire risk. Along the Olympic Peninsula in Washington, the Hoh-Quillayute and Queets-Quinalt sub-basins (both in the Washington Coastal basin) rate high for vulnerability to climate change overall due to their high air temperature ratings and shifts in projected flow regime, as is the case for the North Fork John Day sub-basin (John Day basin, Oregon).

Table 2. Examples of low and high sub-basin climate change vulnerability ratings. Color-coding aligns with the classifications in Figures 4 – 7, above.

Basin	Sub-basin	Air Temperature	Flow Regime Change	Wildfire Risk	Overall Climate Change Vulnerability
Sub-basins with low climate change vulnerability ratings					
Deschutes	Lower Crooked	1st Quantile	Rain:Rain	Low	1st Quantile
Upper Snake	Portneuf	1st Quantile	Transition:Transition	Moderate	1st Quantile
Puget Sound	Puyallup	4th Quantile	Transition:Transition	Low	1st Quantile
Southern Oregon Coastal	North Umpqua	4th Quantile	Rain:Rain	Low	1st Quantile
Sub-basins with high climate change vulnerability ratings					
Upper Columbia	Upper Columbia-Priest	5th Quantile	Transition:Rain	No fuels or outside of elevation zone	5th Quantile
Upper Snake	Upper Henrys	1st Quantile	Snow:Transition	High	5th Quantile
	Blackfoot	1st Quantile	Snow:Transition	High	5th Quantile
Washington Coastal	Hoh-Quillayute	5th Quantile	Transition:Rain	Low	5th Quantile
	Queets-Quinalt	5th Quantile	Transition:Rain	Low	5th Quantile
John Day	North Fork John Day	4th Quantile	Transition:Rain	Low	5th Quantile

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