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Western Hemlock Zone | t̓əq̓ədiʔac

The western hemlock zone is the most widespread vegetation zone in western Washington. Regionally, this zone extends from British Columbia south through the Cascades and Puget Trough west to the Olympic Peninsula. Douglas fir, western hemlock and western redcedar are the major tree species found in this conifer-dominant forest zone. Despite its name, the western hemlock zone is often dominated by Douglas fir (Franklin and Dyrness 1973).

The current distribution of forest zones and vegetation types is driven by the interplay of climate, topography, soil profiles and disturbance events. The western hemlock zone is primarily supported by a maritime climate with mild, wet winters and warm, dry summers. The dominant trees in the western hemlock zone are structurally adapted through tree size, leaf area and needle shape to thrive in this maritime climate. Mild, wet winters, with daytime temperatures that rarely dip below freezing, enable these trees to photosynthesize during the winter months more than in other temperate forest zones. In contrast, photosynthesis during the growing season - and specifically the summer months - is limited due to high vapor pressure deficits,[1] which result in closed leaf stomata that restrict water loss and limit carbon dioxide uptake (Waring and Franklin 1979).

Projected increases in air temperature, changes in seasonal precipitation patterns, declines in snowpack and increasing risk of wildfire are all expected to affect the distribution of the western hemlock zone and its representative tree species.

[1] Vapor pressure deficit is the difference between the amount of moisture in the air and how much moisture the air can hold when fully saturated.

Climate-driven changes to forest distribution

A range of approaches has been developed to model potential changes in the spatial distributions of vegetation communities under future climate scenarios. Below, we describe key findings from available studies predicting future changes in the western hemlock zone within the geography of the Treaty of Point Elliott. These studies rely on two primary approaches for predicting future changes in vegetation communities: dynamic global vegetation models and climatic niche models.

I. Dynamic Global Vegetation Models

Dynamic global vegetation models (DGVMs) have been used in numerous studies to assess how projected changes in climate may affect distribution of vegetation communities across space and time. DGVMs are mechanistic models that integrate many ecosystem processes (e.g., plant biogeography, biophysics, disturbance and vegetation dynamics) to estimate vegetation distributions (Peterson et al. 2014). It is important to note that DGVMs predict changes in vegetation *types*, not individual species. At least five studies have used DGVMs to predict changes in vegetation distributions across the Pacific Northwest. Below we highlight results from each.

- **Rogers et al. (2011)** used MC1, a DGVM, to simulate changes in the most common regional vegetation types by the end of the century for the western two-thirds of Washington and Oregon. The study evaluated changes in vegetation types for three global climate models (GCMs; CSIRO, MIROC 3.2 and Hadley CM3) under a high (A2) emissions scenario. For lands within the Treaty of Point Elliott area, results for all three GCMs show a significant decline in subalpine forest, but disagree on the future of maritime conifer forest (e.g., Douglas-fir, western hemlock, Pacific silver fir), projecting its range as being 1) replaced by temperate conifer forest across much of the North Cascades under a cool, wet future (CSIRO); 2) replaced across areas of the Puget lowlands by temperate warm-mixed or subtropical mixed forest under a hot, wet future (MIROC 3.2); or 3) almost completely replaced by temperate conifer forest (e.g., Ponderosa pine, Douglas-fir, lodgepole pine, grand fir) under a hot, dry future (Hadley CM3) (Figure 1).

- **Sheehan et al. (2015)** used MC2, an updated version of MC1, to simulate vegetation under various climate futures and anthropogenic fire suppression across the Puget lowlands, Cascades and North Cascades (as well as other regions in California and Oregon). The authors chose to reclassify the MC2 vegetation types into more coarse categories to facilitate comparison of vegetation cover; this makes direct comparison to results of Rogers et al. (2011) somewhat challenging. During the 21st century, results suggest a shift from predominantly conifer forests[2] to mixed forests[3] in the central Cascades. Results from Rogers et al. (2011) suggest increases in temperate evergreen needleleaf forest throughout the 21st century, while Sheehan et al.'s (2015) results suggest declines in conifer forests (which includes temperate evergreen needleleaf forest). By the 2080s, under a high greenhouse gas scenario (RCP 8.5), models predict that conifer forests are only present in higher elevations of the Cascades (Figure 2). The result discrepancy between Sheehan et al. (2015) and Rogers et al (2011) could be due to differences in climate futures considered (CMIP5 and CMIP3, respectively) or vegetation model parameterizations, or both. Across much of the western northwest region, the projected transition from conifer to mixed forest is associated with increasing temperatures and warmer, drier climates during the summer months, and is also facilitated by the occurrence of wildfire in the subregion.

- **Sheehan et al. (2019)** used MC2 to simulate vegetation shifts, carbon fluxes and wildfires under various future climates across the western third of Washington and Oregon, which included the Puget Lowlands, Cascades and North Cascades. Similar to results from Sheehan et al. (2015), the MC2 model results suggest that, by mid-century, conifer extent across the study area will decrease, and temperate mixed forest extent will increase. These trends are magnified at the end of the 21st century (Figure 3). The rate and pattern of this projected transition from conifer to temperate mixed forest is also observed in the wildfire scenario and the carbon dioxide fertilization effect scenario; this suggests the projected vegetation shifts are being driven solely by climate change, and that the projected change in vegetation cover will likely occur regardless of how the western fire regime shifts. This is in contrast to results from Sheehan et al. (2015) and Bachelet et al. (2015) showing vegetation shifts are driven by fire regimes.

- **Halofsky et al. (2018)** used both empirical and process-based modeling approaches to evaluate vegetation projections in western Washington, under three different climate futures and management strategies. This study used simulated shifts in vegetation using MC2 and a climate-informed state-and-transition simulation model (cSTSM), which simulates vegetation shifts with climate, wildfire and management. The authors reclassified the MC2 vegetation types with a coarse-scale plant classification, which makes direct result

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[2] The conifer forest vegetation class includes the subalpine, maritime evergreen needleleaf forest (maritime conifer forest in Rogers et al. 2011), temperate evergreen needleleaf forest, and cool needleleaf forest MC2 vegetation types.

[3] This includes the cool mixed forest vegetation class which is composed of the following MC2 vegetation types: temperate cool mixed forest, and the warm mixed forest vegetation class which is composed of the following MC2 vegetation types: temperate warm mixed forest and subtropical mixed forest.

comparison with other studies challenging. MC2 results predict that vegetation distribution will diverge from historical conditions throughout the 21st century, with the western hemlock zone experiencing losses in some low elevation areas as the Douglas fir zone[4] expands, but moving up in elevation in the Cascades into the Sitka spruce zone and Pacific silver fir zone (Figure 4).

In the cSTSM simulations without fire suppression the forest zone remains relatively stable throughout the 21st century: the Douglas fir zone is projected to expand to a lesser degree than projected with MC2, and the western hemlock zone is projected to remain the dominant vegetation type in western Washington.

- **Shafer et al. (2015)** used Lund-Postsdam-Jena (LPJ), a DGVM, to predict potential vegetation shifts within the northwest U.S and southwest Canada for the end of the century under a high emissions scenario (A2) for five GCMs. Results vary by GCM (Figure 5), but a decline in cool forest and almost total loss of cold forest in the upper elevations of the North Cascades is seen across all GCMs, and retention of cool forest in the Cascades is seen for all but one GCM. Three GCMs show retention of maritime cool forest (the functional type most likely to correspond with the western hemlock zone) across the Puget lowlands and western slopes of the Cascades, but two GCMs show it being extensive;y replaced by cool open forest in the Puget lowlands. While these results are comparable to other DGVM studies in that they predict the persistence of forest types in western Washington, the classification of these forest types differs from other studies.

II. Climatic Niche Models

Climatic niche models define climatic conditions for a species' or biome's current distribution and then project where on the landscape those conditions are expected to occur in the future. These relatively coarse models are based on simple correlations between climatic conditions and the distributions of species or biomes, and thus are often critiqued for their lack of biological realism compared to process-based models such as DGVMs.

- **Rehfeldt et al. (2012)** used climate niche vegetation models to predict regional biome distributions under low (B1 and B2) and high (A2) emissions scenarios. By the 2090s (2086-2095), for the consensus GCM under a high greenhouse gas

[4] Primarily refers to dry temperate to almost continental climates in western Washington. Dominant tree species are Douglas fir or lodgepole pine. Pacific madrone, western hemlock, and western white pine may also be present.

scenario, western Washington is projected to transition from the predominant coastal conifer forest biome to a low to mid-elevation conifer forest.

- **Littell et al. (2010)** incorporated results from Rehfeldt et al. (2006) to identify how climate suitability for Douglas fir is projected to shift with climate change. Increasing air temperatures and drier summer conditions are likely to reduce the area of climatically suitable habitat for Douglas fir in the lower elevations of the Puget Sound region, specifically the south Puget Sound by the end of the 2060s (Figure 6). Additionally, this study found that 85% of the Washington landscape that is currently suitable for at least one pine species[5] is projected to be climatically unsuitable for one or more current pine species by the 2080s (Figure 7).

Synthesis & Key Conclusions

- Available model outputs generally agree that coniferous forest is likely to remain the dominant forest type in western Washington. However, there is limited model agreement on predicted conifer forest type (e.g., maritime evergreen needleleaf forest, temperate evergreen needleleaf forest, cool needleleaf forest) and extent.
- Overall, available model outputs suggest the climate will be less suitable for species in the western hemlock vegetation zone by the end of the 21st century. Although some results (e.g., cSTSM results from Halofsky et al. 2018) suggest the forest zone may be relatively stable throughout the century, other studies predict the forest zone will move to higher elevations, into portions of the landscape that have historically been characterized as the Pacific silver fir zone.

Opportunities and Considerations for Applying Results

- *Appropriate Scale of Interpretation:* Generally speaking, spatial model outputs should not be assumed to be accurate or useful at the scale of individual pixels; rather, results should be interpreted at a more regional scale and used as an indicator of the expected direction or magnitude of projected changes in a species' or community's distribution.
- *Supporting Climate Adaptation:* Model outputs provide essential data that can be used to inform climate adaptation. For example, geographic regions expected to remain suitable for the western hemlock zone as the climate changes could be managed for use as *in situ* seed banks or key source populations as the zone's range moves upward in latitude and/or elevation. Identifying and protecting western hemlock zone refugia expected to persist through the 21st century may also help enhance connectivity between shifting areas of suitable habitat and along climatically suitable habitat corridors (Magness and Morton 2018).

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[5] Lodgepole pine is considered a minor species in the western hemlock zone and was included in this analysis.

- *Informing Management Goals:* Tulalip Tribes' natural resource managers may want to consider whether their forest management goals should be revisited in light of projected changes to priority species and communities, particularly if existing goals and strategies rely on historical conditions as the baseline for natural resource management. For example, should goals focus on *resisting* projected changes in distributions (e.g., which could require identifying and enhancing local climatic refugia where species may persist); on *accepting* projected changes and supporting species/communities in shifting to new distributions (e.g., by enhancing habitat connectivity to promote dispersal and range migration to newly suitable habitat); or on actively *directing* species and communities toward projected future distributions (e.g., via translocation / assisted migration) (Schuurman et al. 2020). Revisiting goals and strategies in light of projected changes may help ensure the success of management actions and continued provision of natural and cultural resources important to the Tulalip Tribes.
- *Managing Uncertainty:* As highlighted in the maps provided in the appendix, there are areas of western Washington where there is disagreement among models. When there is model disagreement it becomes challenging to determine which management decisions promise the best outcome. Under these circumstances, the best approach may be to employ a suite of adaptation actions that account for multiple possible futures. This approach, commonly referred to as 'bet-hedging,' seeks to increase the likelihood of an acceptable outcome given future uncertainties (Glick et al. 2011).
- *Utility for Outreach and Engagement:* Results may be useful for raising awareness about the impacts of climate change among natural resource managers and the general public. For example, knowledge of projected changes may help shift natural resource management strategies and policies, or build public buy-in for management strategies aimed at directing change to facilitate shifts in distributions where models suggest that change is inevitable.

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Appendix A. Figures and Tables.

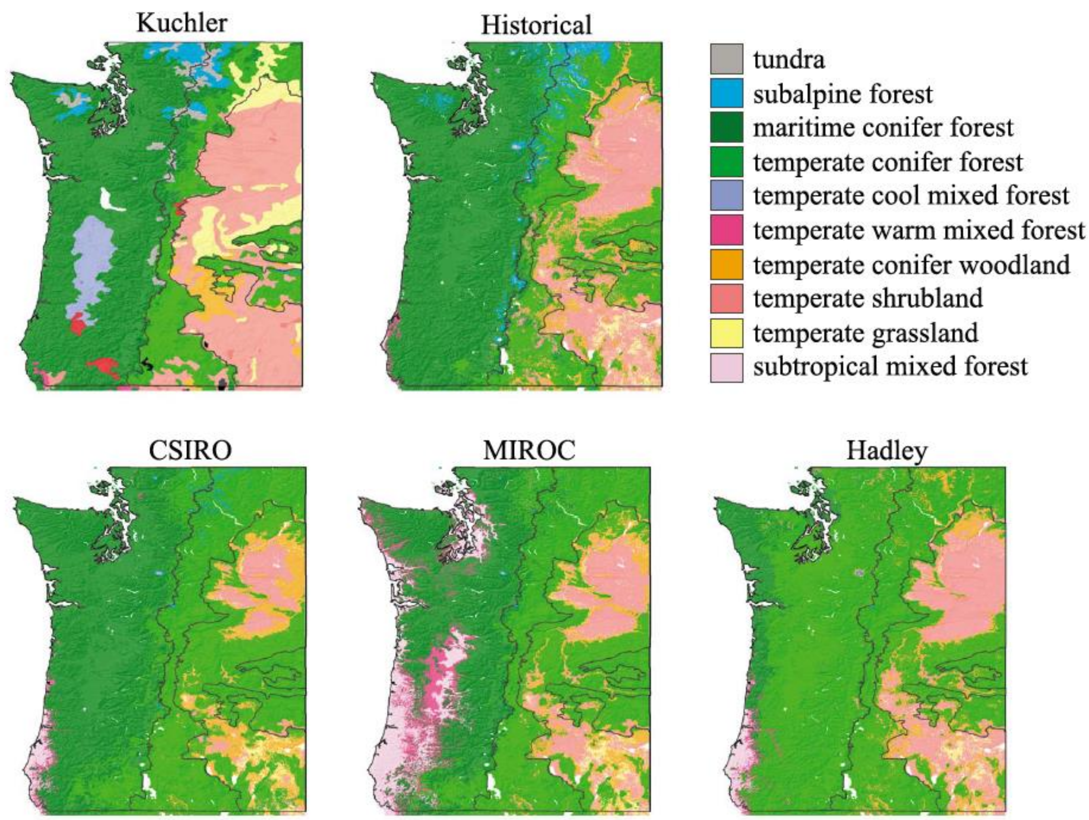

Figure 1. Rogers et al. (2011). Simulated vegetation types modeled using full fire for historical (1971-2000) and future (2070-2099) periods for three GCMs (CSIRO Mk3, MIROC 3.2 medres, and Hadley CM3) under the A2 greenhouse gas scenario. Figure from Rogers et al. (2011).

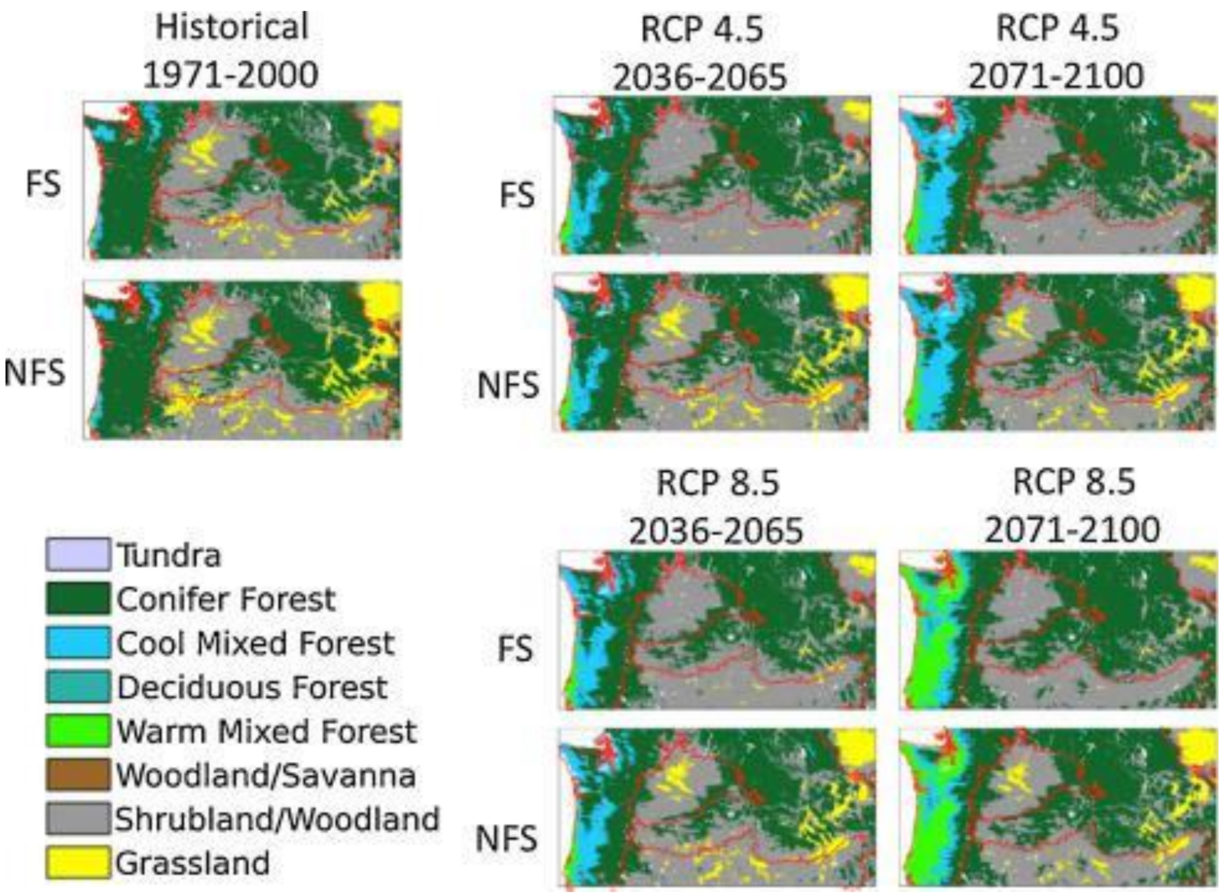

Figure 2. Sheehan et al. (2015). Simulated vegetation classes for historical time period and the mode of results from 20 GCMs for two representative concentration pathways (RCPs). Modes include results of runs produced using all climate futures (FS, fire suppression; NFS, no fire suppression). Figure from Sheehan et al. (2015).

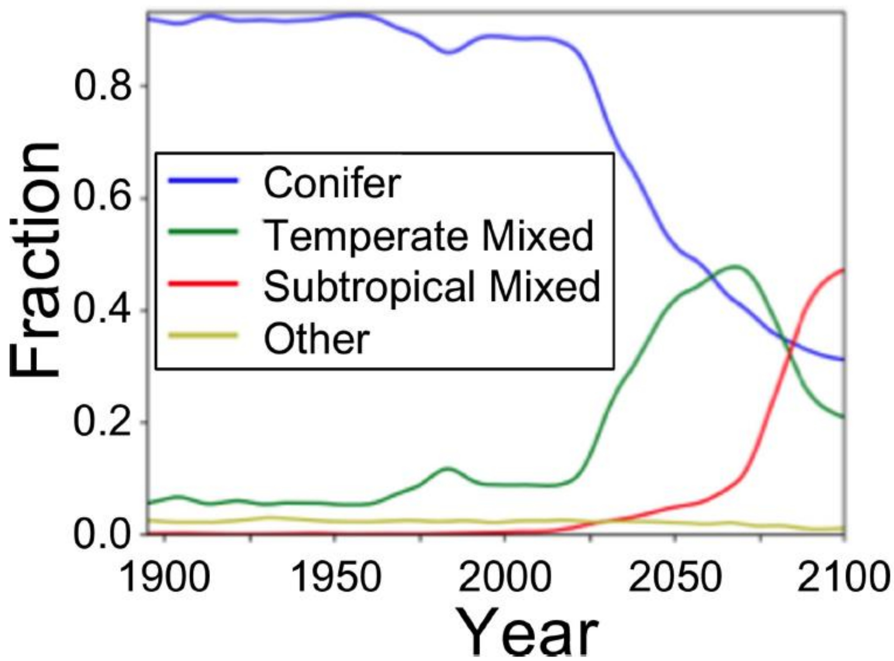

Figure 3. Sheehan et al. (2019). Vegetation class mix over time for the full fire with CO_2 fertilization scenario. All other scenarios yield virtually identical results. Figure from Sheehan et al. (2019).

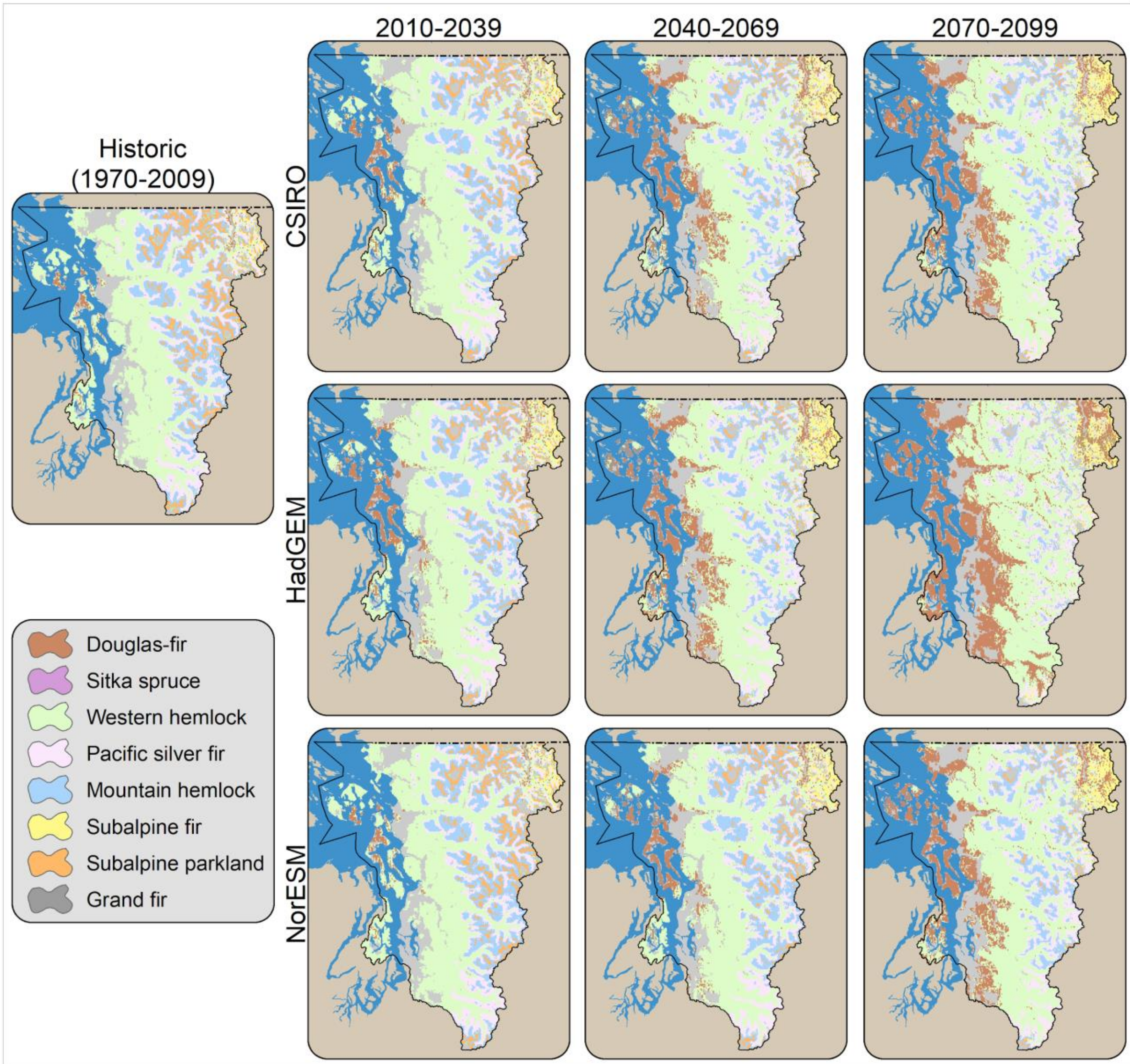

Figure 4. Halofsky et al. (2018). MC2 output for forest zones based on three GCMs (30-year modal values). Maps represent vegetation potential based on biophysical properties and climate. Data: Halofsky et al. (2018). Map created by UW Climate Impacts Group.

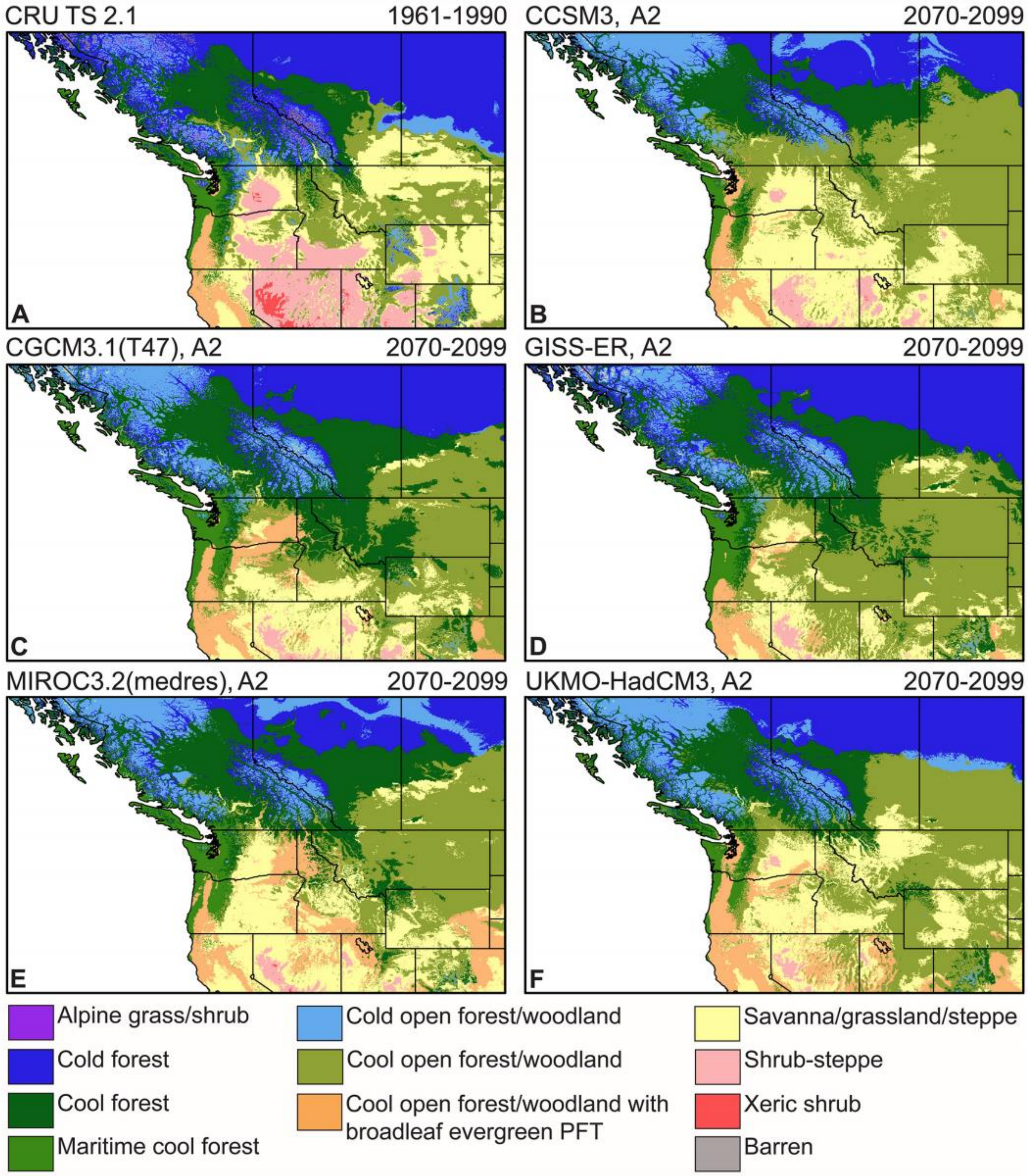

Figure 5. Shafer et al. (2015). LPJ simulated vegetation. Vegetation was simulated for (A) 1961–1990 using CRU TS 2.1 climate data, and for (B-F) 2070–2099 using climate projections from CCSM3, CGCM3.1(T47), GISS-ER, MIROC3.2(medres), and UKMO-HadCM3 coupled atmosphere-ocean general circulation models (AOGCMs). PFT = plant functional type.

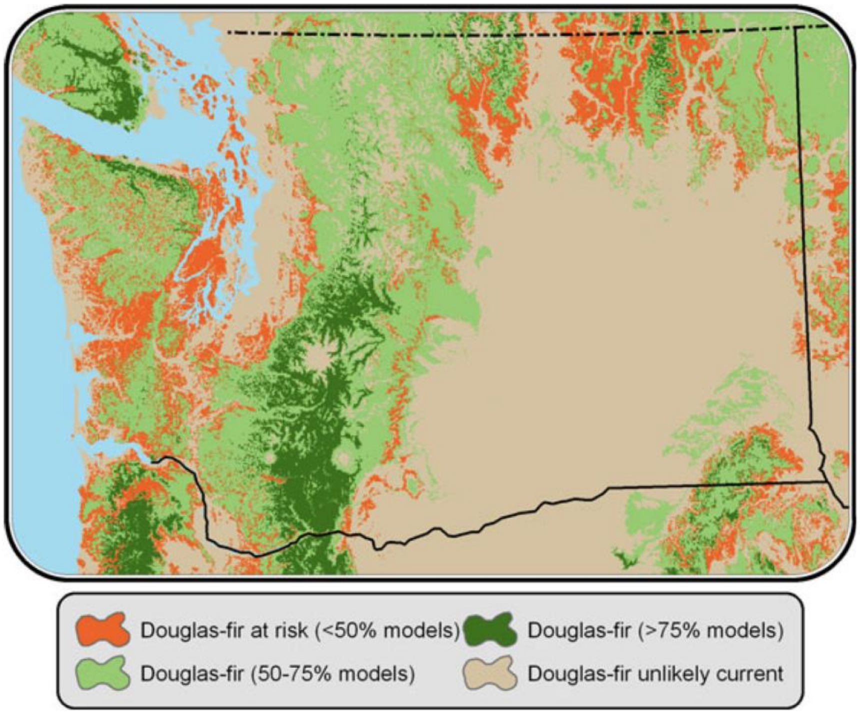

Figure 6. Littell et al. (2010). Changes in climatic suitability for Douglas fir predicted by climatic niche models. Data: Rehfeldt et al. (2006), analysis after Littell et al. (2010).

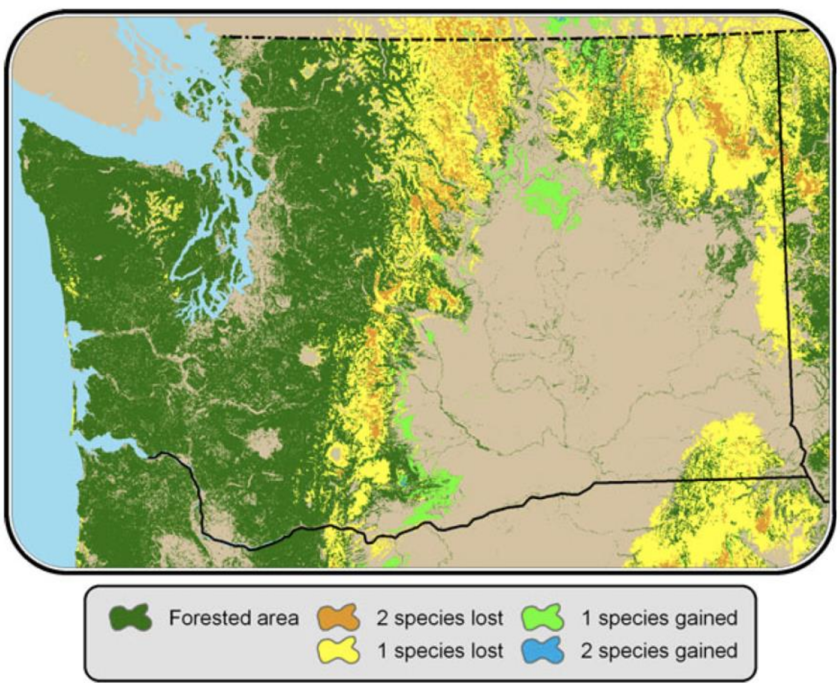

Figure 7. Littell et al. (2010). Changes in climatic suitability for multiple pine species predicted by climatic niche models. Data: Rehfeldt et al. (2006), analysis after Littell et al. (2010).

Appendix B. Conceptual Model of Climate Impacts on the Western Hemlock Zone

We created a conceptual model that summarizes the ecological and climatic drivers of western hemlock zone abundance in western Washington. This model can be used to identify intervention points where management action or traditional practices could help reduce climate risks to the western hemlock zone.

In the model, green arrows indicate a positive correlation between linked drivers or processes (i.e., as variable *x* increases variable *y* increases; orange arrows indicate a negative relationship between variables (i.e., as variable *x* increases, variable *y* decreases); and dashed gray arrows indicate the absence of a directional trend or an area where additional research is needed. Light red boxes are used to highlight human management activities (e.g., forest management or traditional practices) that directly or indirectly influence the abundance of the western hemlock zone in western Washington.

Conceptual Model of Climate Impacts to the Western Hemlock Zone | t̓əq̓ədiʔac