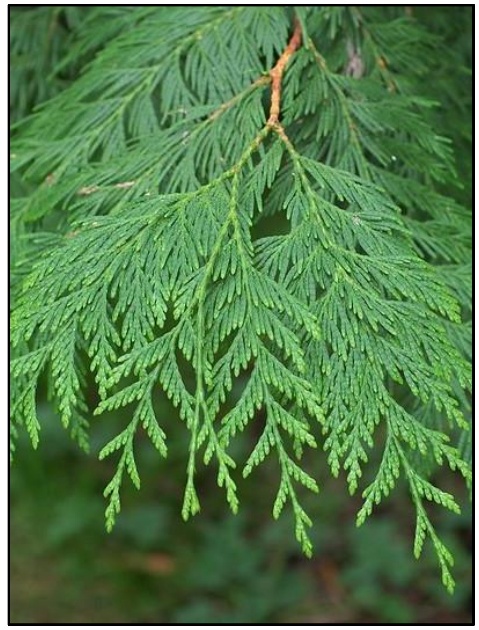
TREATY RIGHTS & GOVERNMENT AFFAIRS

Western Redcedar | x̌payʔac



Western redcedar (*Thuja plicata*) is the largest and, after yellow cedar, second longest-lived tree species in the Pacific Northwest; they commonly grow 60 m tall (Waring and Franklin 1979) and are capable of living over 1,500 years (Van Pelt 2007). Western redcedar-dominated forests are exclusively found in coastal regions of Washington and British Columbia, where moisture availability is high and the last major fire disturbance event occurred more than 1000 years ago. Within the Puget Sound and Cascades Range, however, forests older than 500 years are not typical. The species is most often found in low-lying areas from sea level to 600 m (Cheney 2016). Inland from the coast, Western redcedar-dominated areas are typically restricted to forested wetland areas or alluvial forests in the North Cascades. Western redcedar is usually found growing with western hemlock and Douglas fir and an understory of ferns, huckleberries and devil's club (Van Pelt 2007).

Projected increases in air temperature, changes in seasonal precipitation patterns and declines in snowpack are expected to affect the distribution of Western redcedar.

Climate-driven changes in western redcedar distribution

A range of approaches has been developed to model potential changes in the geographic distributions of species and vegetation communities under future climate scenarios. Below, we describe key findings from available studies predicting future changes in the range of western redcedar within the geography of the Treaty of Point Elliott. These studies rely on two primary approaches for predicting changes to species and vegetation communities (though some studies incorporate components of both approaches): statistical-based models and process-based models.

I. Statistical-Based Models

Statistical-based species distribution models, also known as climatic niche or bioclimatic envelope models, use relationships between species occurance data and bioclimatic variables (e.g., temperature, precipitation) to describe a species' bioclimatic niche. These models are solely correlative, describing the relationship between bioclimatic conditions across a species' current distribution and then extrapolating from this to predict the species' future distribution based on projected climatic conditions; they do not include the processes (e.g., physiological or ecological) that may also influence species distributions.

- **Gray and Hamann (2013)** used a bioclimatic envelope model to project latitudinal and elevational shifts in suitable habitat for western redcedar under four emissions scenarios (AIFI, A2, B1, B2) for the 2020s, 2050s and 2080s, relative to average conditions between 1961-1990, using five global climate models. By the 2050s (2041-2070), suitable habitat for the Western redcedar population spanning the Puget Sound and southern BC coast is projected to shift 568 km (353 miles) northward or 250 m (820 ft) upward in elevation (relative to the 1961-1990 reference projection, averaged over 18 climate change scenarios). See Figure 1, 2, 3 for maps of projected shifts in suitable habitat by the 2020s, 2050s and 2080s, respectively.

- **McKenney et al. (2011)** used a bioclimatic envelope model to project shifts in the envelopes of North American tree species resulting from the impacts of climate change. Under a moderate greenhouse gas scenario (RCP 4.5), by the 2020s climate envelope models project a loss of core western redcedar habitat in low elevation regions of Puget Sound (Figure 4, 5). By the 2040s, the projected range no longer includes low elevation regions of Puget Sound and the core habitat within western Washington is projected to decline (Figure 4, 5). By the 2080s, the projected range and core habitat for western redcedar shrinks and is primarily projected to occur in higher elevation areas (Figure 4, 5).

- **Kim et al. (2012)** used a bioclimatic envelope model to project shifts in the western redcedar seed transfer zone in the Puget Sound area. These were projected under three emissions scenarios (B2, A1B, and A2) for six global climate models for the 2020s, 2050s and 2080s. Model results suggest the western redcedar seed zone within the Puget Sound region is predicted to contract significantly by the end of the 21st century under all three emission scenarios. Models project other seed zones will not replace this shrinking zone, resulting in a seed zone gap that can be seen in Figure 6. Models also project a mismatch between the current and future seed zone climates for the Skagit and Twin Harbor regions starting mid-century. In contrast, projected climate conditions will be most similar to the Toutle seed zone, which suggests that Toutle seed transfer zones may be an appropriate area to source seeds within the Puget Sound region. The "Seedlot Selection Tool", developed by Oregon State University and the Forest Service, may help natural resource managers match seedlots with planting sites based on climatic information.

II. Process-Based Models

Process-based models, also known as mechanistic or biophysical models, focus on the processes (e.g., physiological, disturbance, species interactions) that drive changes in vegetation communities. There are many different types of process-based models, including dynamic global vegetation models (DGVMd), biogeochemical models and gap models. DGVMs predict changes in vegetation types rather than individual species, integrating many ecosystem processes (e.g., plant biogeography, biophysics, disturbances and vegetation dynamics) to estimate future distributions. Biogeochemical models are typically used to simulate the effects of climate change on net primary productivity and carbon flux and storage. Gap models simulate the establishment, growth and mortality of individual trees on small patches of land (e.g., an individual canopy gap or stand of trees) as a function of biotic (competition) and abiotic factors (climate and soils); they are often used to explore climate impacts on forest structure, biomass and composition.

- **Case and Lawler (2017)** used Lund-Postsdam-Jena (LPJ; Shafer et al. 2015), a dynamic global vegetation model (DGVM), to predict potential vegetation shifts within the northwest U.S and southwest Canada under a high emissions scenario (A2). LPJ reclassifies vegetation types used in MC2 (another DGVM) into more coarse categories. The authors modeled future tree climatic niches for five global climate models (GCMs; UKMO-HadCM3, CSIRO, GISS-ER, CGCM3.1, CCSM3, and MIROC 3.2) under a high (A2) greenhouse gas emissions scenario. Results from climatic niche models refined by the DVGM estimate that current Western redcedar distribution will contract by over 20%.

- **Coops and Waring (2011)** applied a hybrid modeling approach that combines bioclimatic envelope models with mechanistic models that employ statistical classification tree methods. Predicted changes in western redcedar range were generated for the 2020s, 2050s and 2080s under the A2 and B1 emissions scenarios for the Canadian GCM. Western redcedar range is predicted to expand up to 800,000 km2 by the end of the 21st century, while maintaining most of the historical range (Figure 7, 8, 9). The predicted range expansion of the species may help highlight regions that are favorable for migration.

- **Hargrove and Hoffman (2005)** used a geographic clustering technique which is a data-driven, empirical approach that combines GIS with a statistical package to generate ecoregions, or areas which share similar environmental variables (e.g., plant-available water capacity, soil organic matter, mean precipitation during the growing season, degree-day heat sum during the growing season, elevations, extremes of annual temperature, etc.). Results from this study show how western redcedar habitat may shift under different climate futures. By mid-century under the A1F1 emissions scenario, suitable habitat for western redcedar is projected to decline slightly at low elevation zones within the Tulalip Tribes' usual and accustomed area (Figure 10 and 11). By 2100 under the A1F1 emissions scenario, this trend in western redcedar habitat is projected to continue, with further loss of suitable habitat in low elevation areas.

- **Crookston et al. (2010)**, created a gap model that used modifications to the widely used Forest Vegetation Simulator (FVS), an individual tree growth model (i.e., Climate-FVS) to consider the effects of climate change on tree growth, death and regeneration. Climate data from three GCMs and three emission scenarios (A2, A1B and B1) was used to estimate future climates for three time horizons: 2030s, 2060s and 2090s. Maps are available in Figure 12 and Figure 13. The Climate-FVS model projects that by the 2060s, low elevation areas in western Washington will no longer be viable for western redcedar. Viable habitat will shift up in elevation and will move to more northern latitudes in British Columbia (Figure 12 and 13). By the 2090s, these trends are exacerbated and in many cases, viable western redcedar habitat in western Washington is solely projected to occur in the high elevations of the North Cascades.

Synthesis & Key Conclusions

- Available model outputs generally agree that *suitable habitat for western redcedar is likely to decline in western Washington, specifically in lower elevations of the Puget Sound.* However, there are differences in the projected extent of this decline.
- Generally, available model outputs suggest the climate will be less suitable for western redcedar by the end of the 21st century. Although some results (e.g., Hargrove and Hoffman 2005) suggest the forest zone may be relatively stable throughout the century, *most studies predict the range of western redcedar will move to higher elevations and/or to more northern latitudes*.

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 western redcedar as the climate changes could be managed for use as *in situ* seed banks or key source populations as the species' range moves upward in latitude and/or elevation. Identifying and protecting western redcedar habitat 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).
- *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.

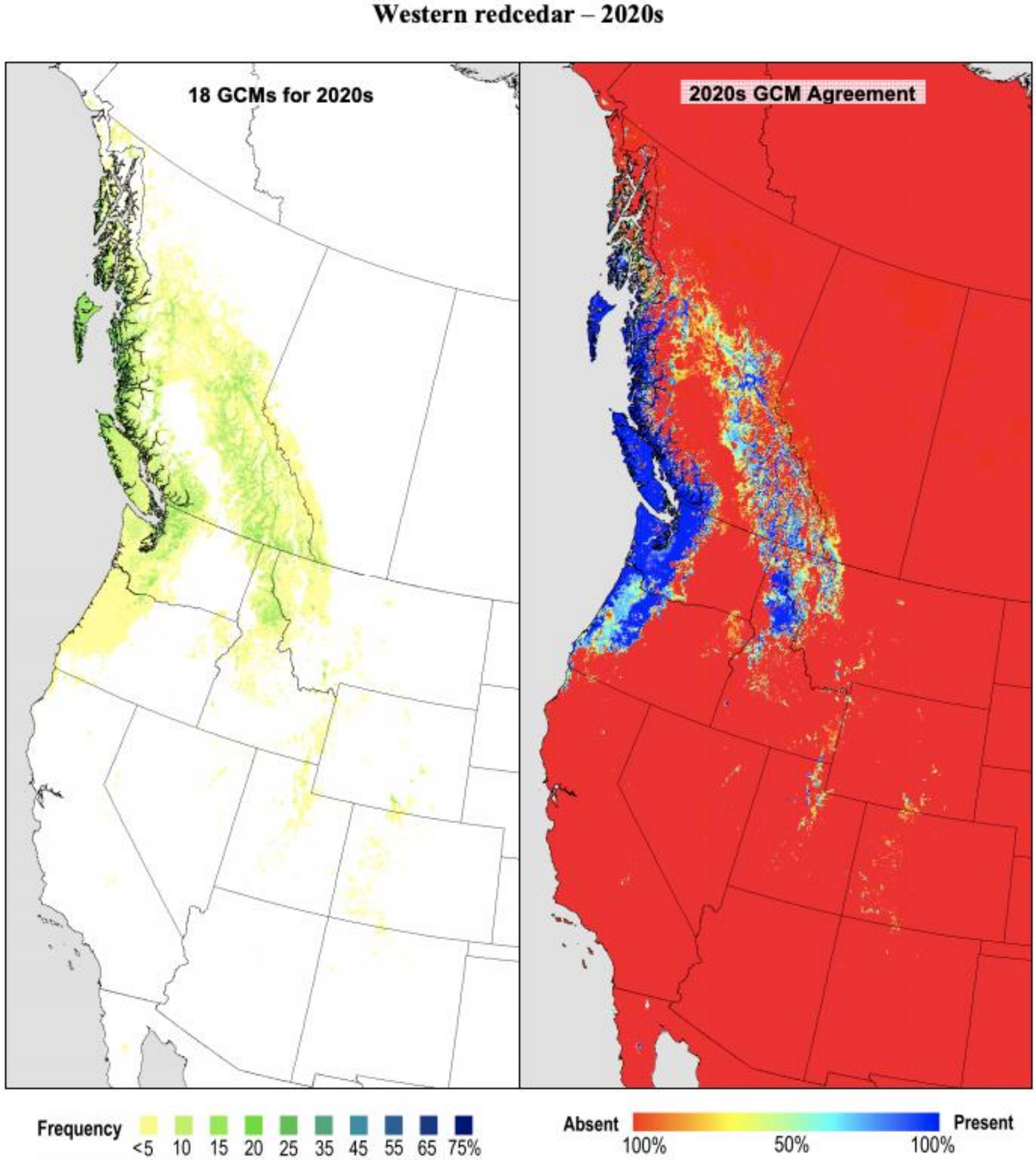

Figure 1. Gray and Hamann (2013). Projected habitat of western redcedar for the 2011–2040 normal period according to 18 climate change projections. The left image is an average expected frequency (% canopy cover projected to the ground). The right image represents agreement of species presence/absence projections for 18 general circulation models.

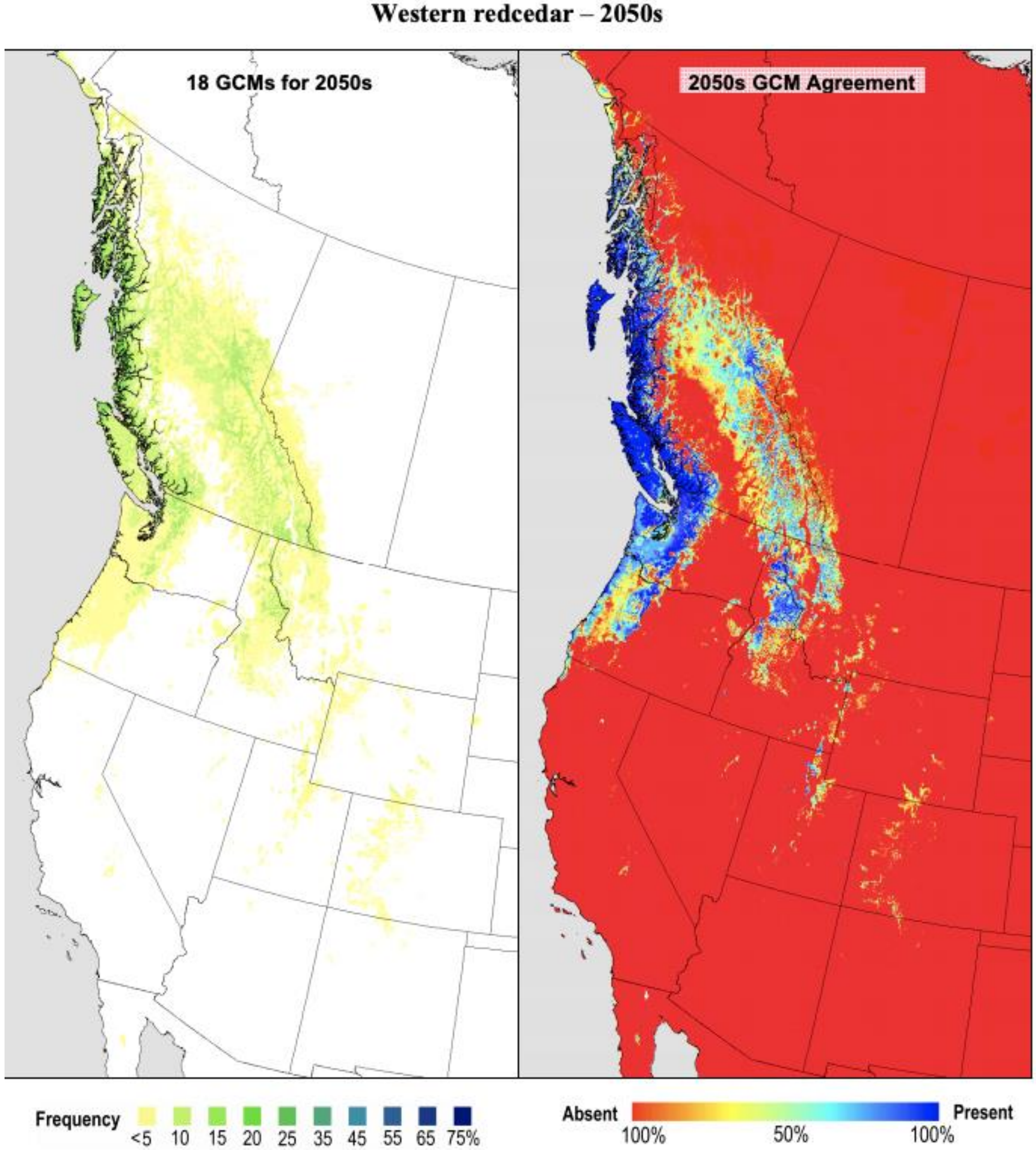

Figure 2. Gray and Hamann (2013). Projected habitat of western redcedar for the 2041–2070 normal period according to 18 climate change projections. The left image is an average expected frequency (% canopy cover projected to the ground). The right image represents agreement of species presence/absence projections for 18 general circulation models.

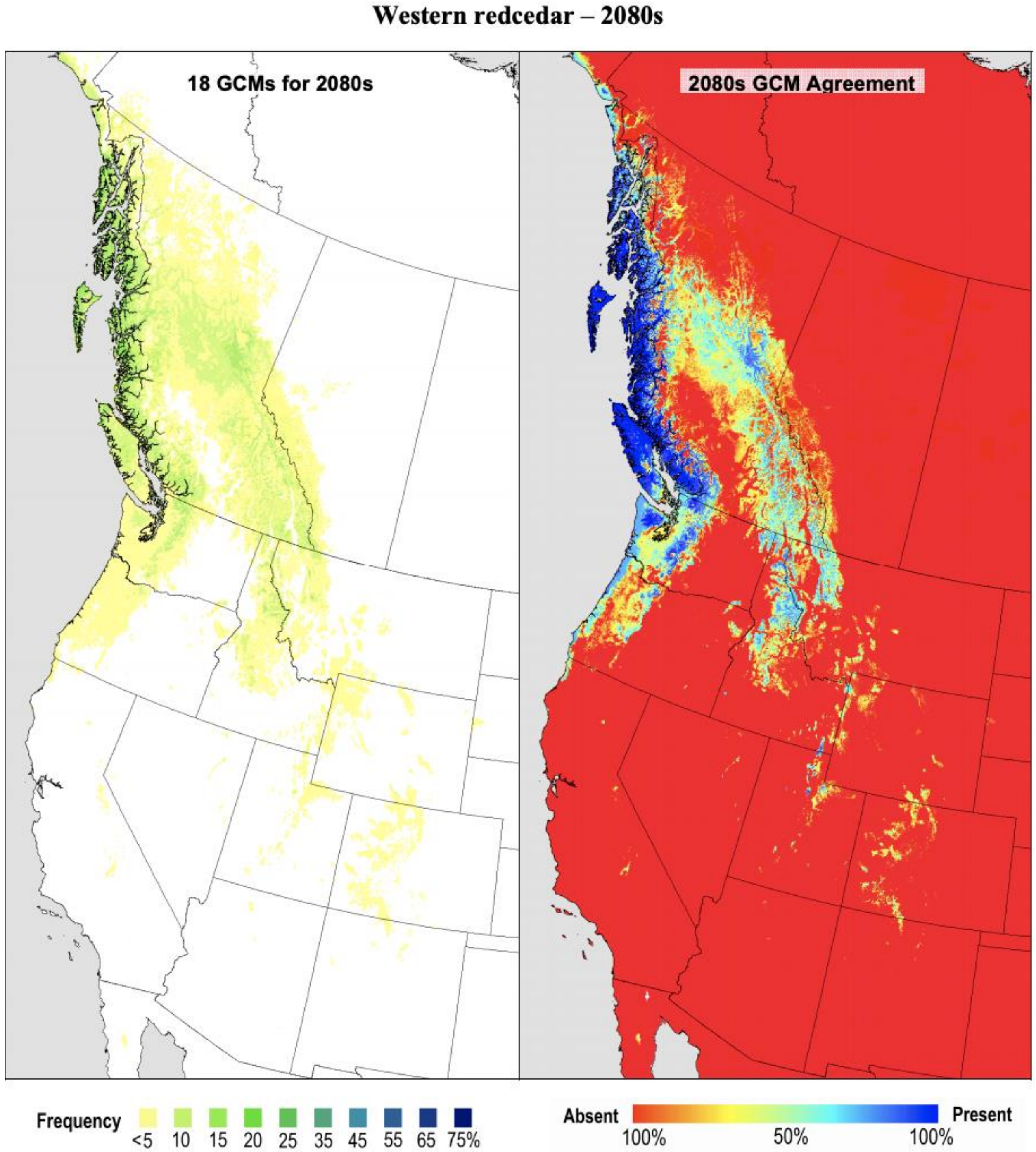

Figure 3. Gray and Hamann (2013). Projected habitat of western redcedar for the 2071–2100 normal period according to 18 climate change projections. The left image is an average expected frequency (% canopy cover projected to the ground). The right image represents agreement of species presence/absence projections for 18 general circulation models.

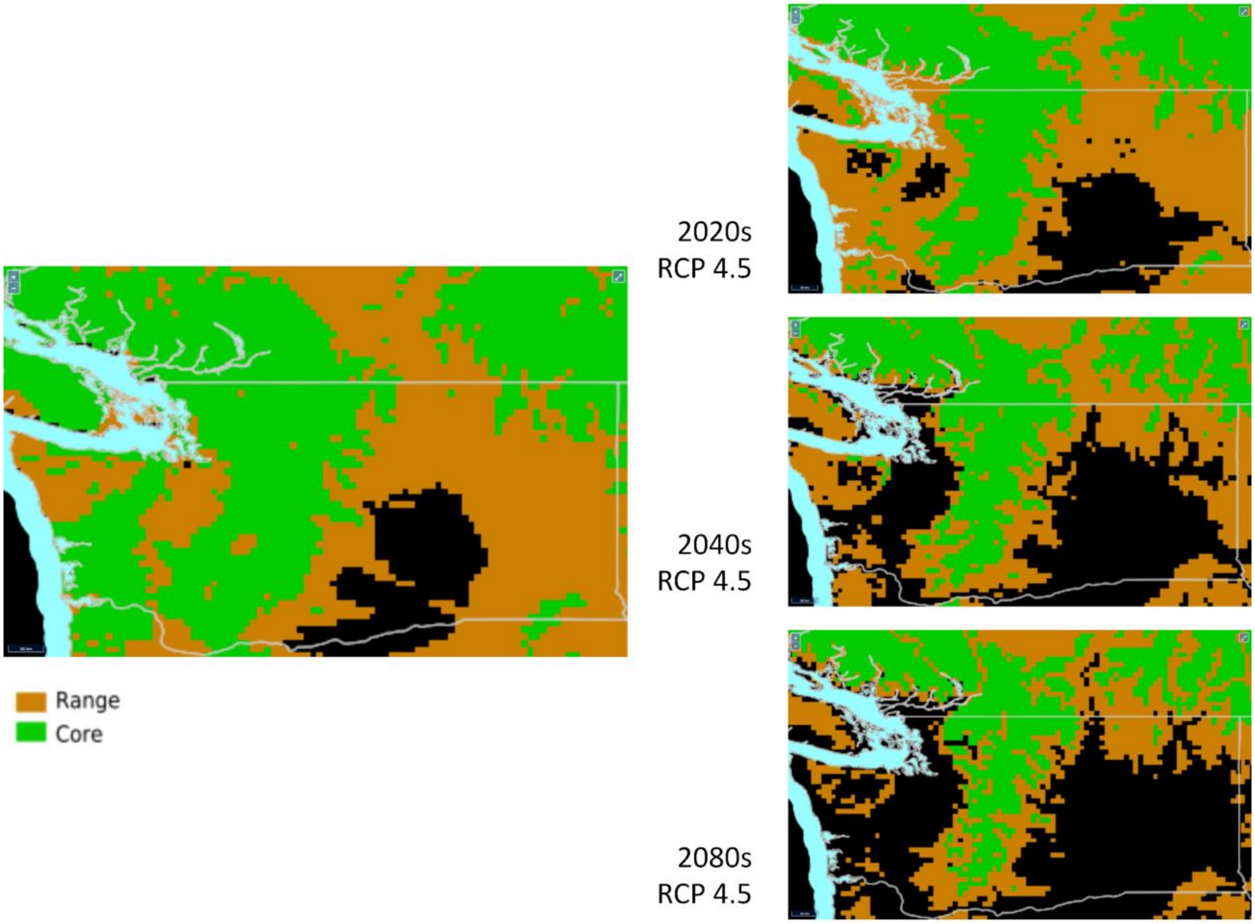

Figure 4. Climate envelopes (full range and core range) for western redcedar. Projections are generated under RCP 4.5 for the 2020s, 2040s, and 2080s using a GCM composite (McKenney et al. 2011).

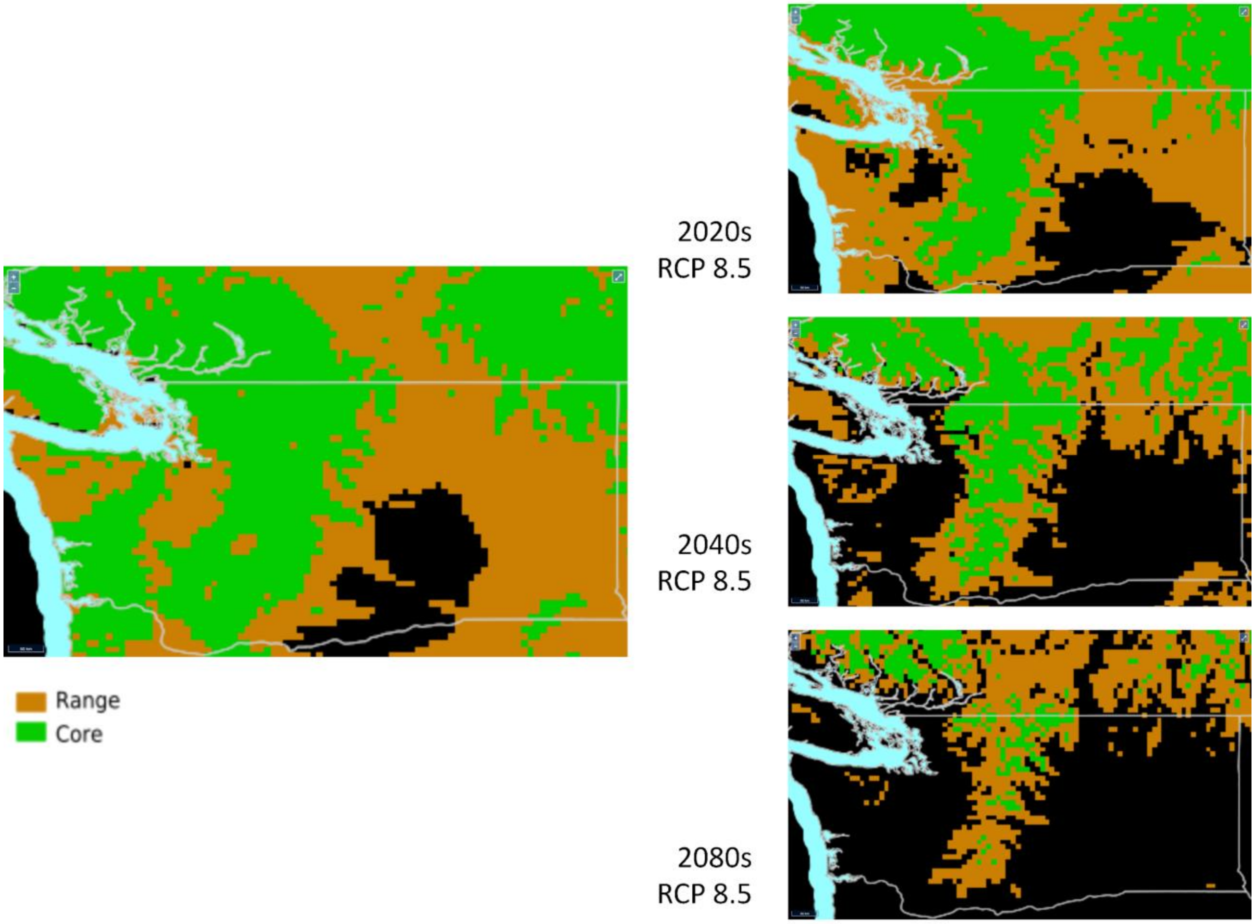

Figure 5. Climate envelopes (full range and core range) for western redcedar. Projections are generated under RCP 8.5 for the 2020s, 2040s, and 2080s using a GCM composite (McKenney et al. 2011).

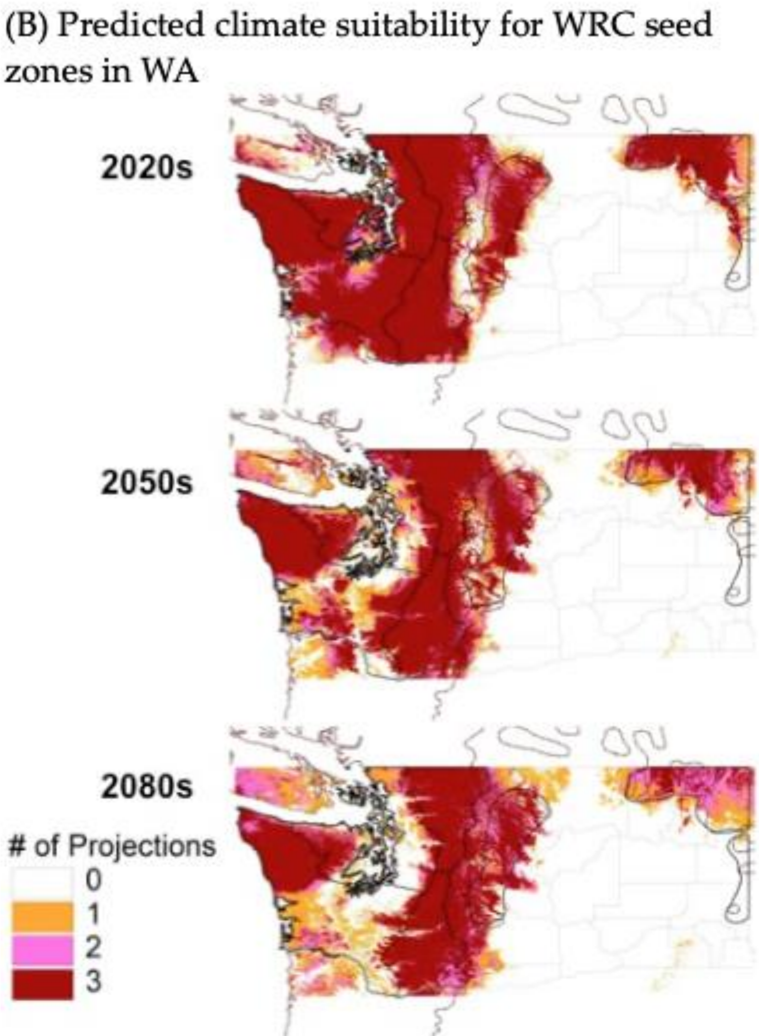

***Figure 6*. Predicted climate suitability for western redcedar seed zones in Washington. Three future climate projections (CCCMA-CGCM2 for A2 and B2 emission scenarios and MPI-ECHAM5 for A1B emission scenario) were used and their agreement is noted by colors: dark red (all three agreed), pink (two agreed), orange (one predicted this area to match the climate conditions of current range), and white (non predicted this area to match the current rage climate conditions). Mismatch between current and future climates of seed zones within WA State is predicted to emerge in the mid 21st century mostly from the Puget Sound area (Kim et al. 2012).

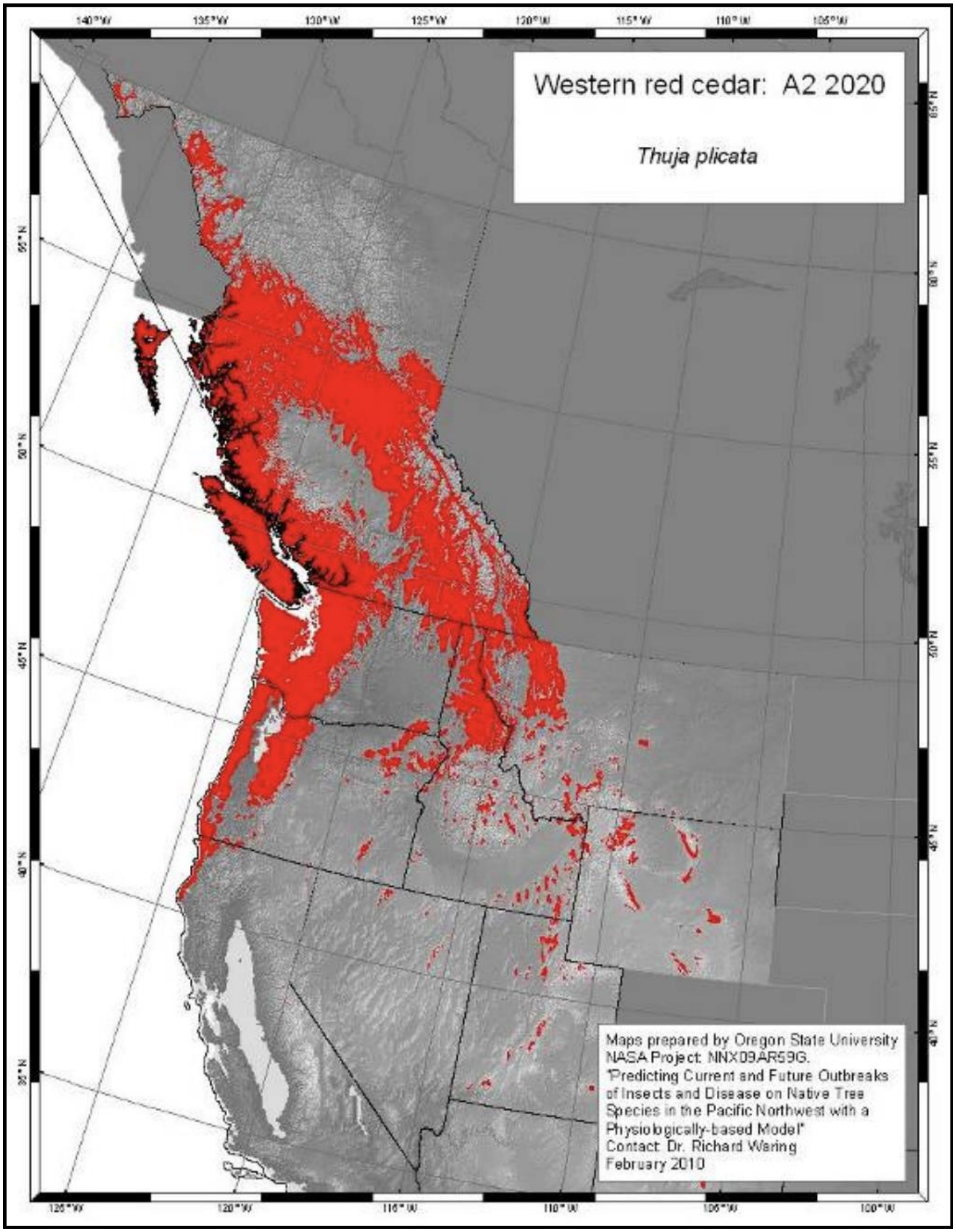

Figure 7. Coops and Waring (2011). Predicted range of western redcedar by 2020s under the A2 emissions scenario using CGCM3. Maps available: http://www.pnwspecieschange.info/linked/westernredcedarresults.pdf

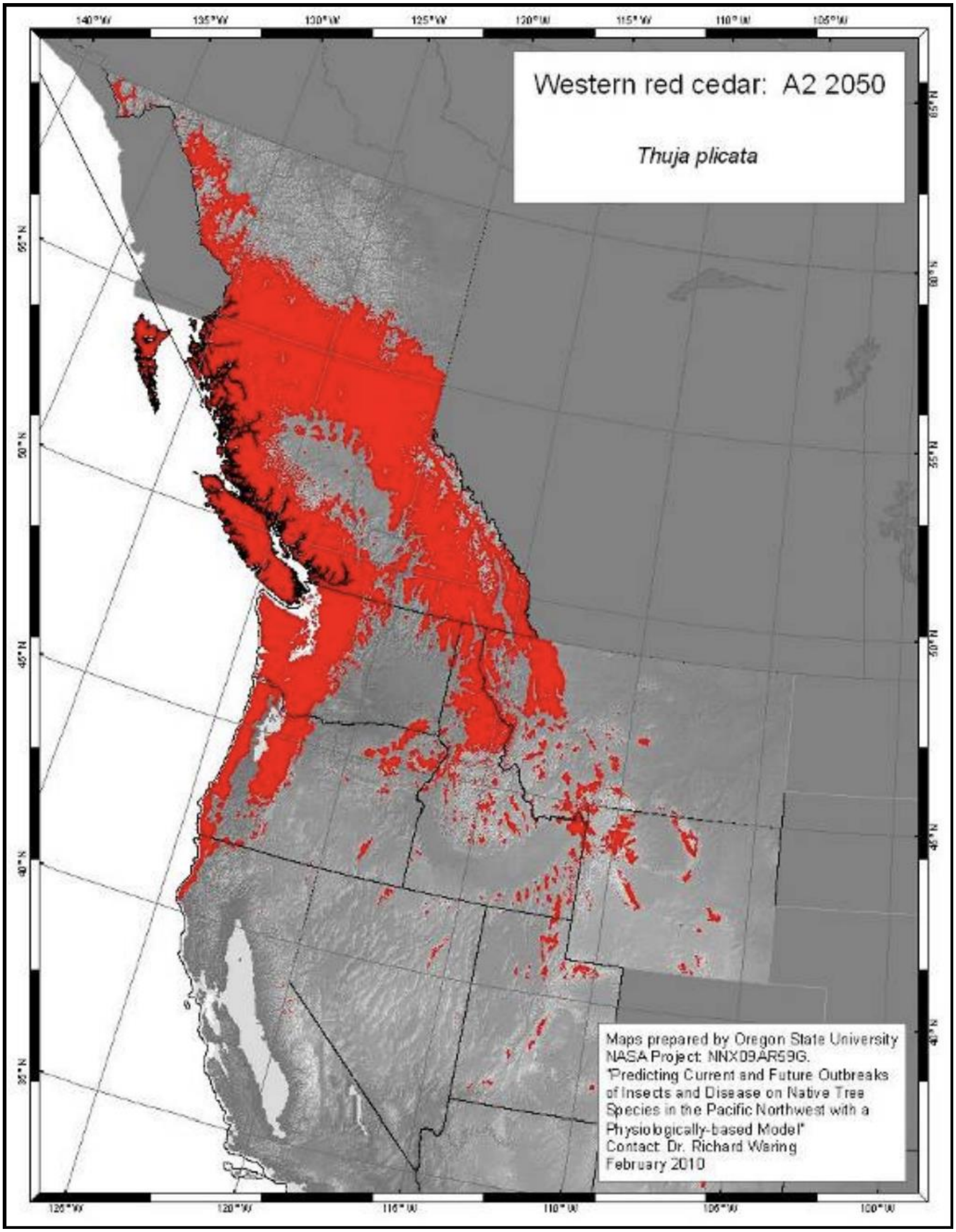

Figure 8. Coops and Waring (2011). Predicted range of western redcedar by 2050s under the A2 emissions scenario using CGCM3. Maps available:
http://www.pnwspecieschange.info/linked/westernredcedarresults.pdf

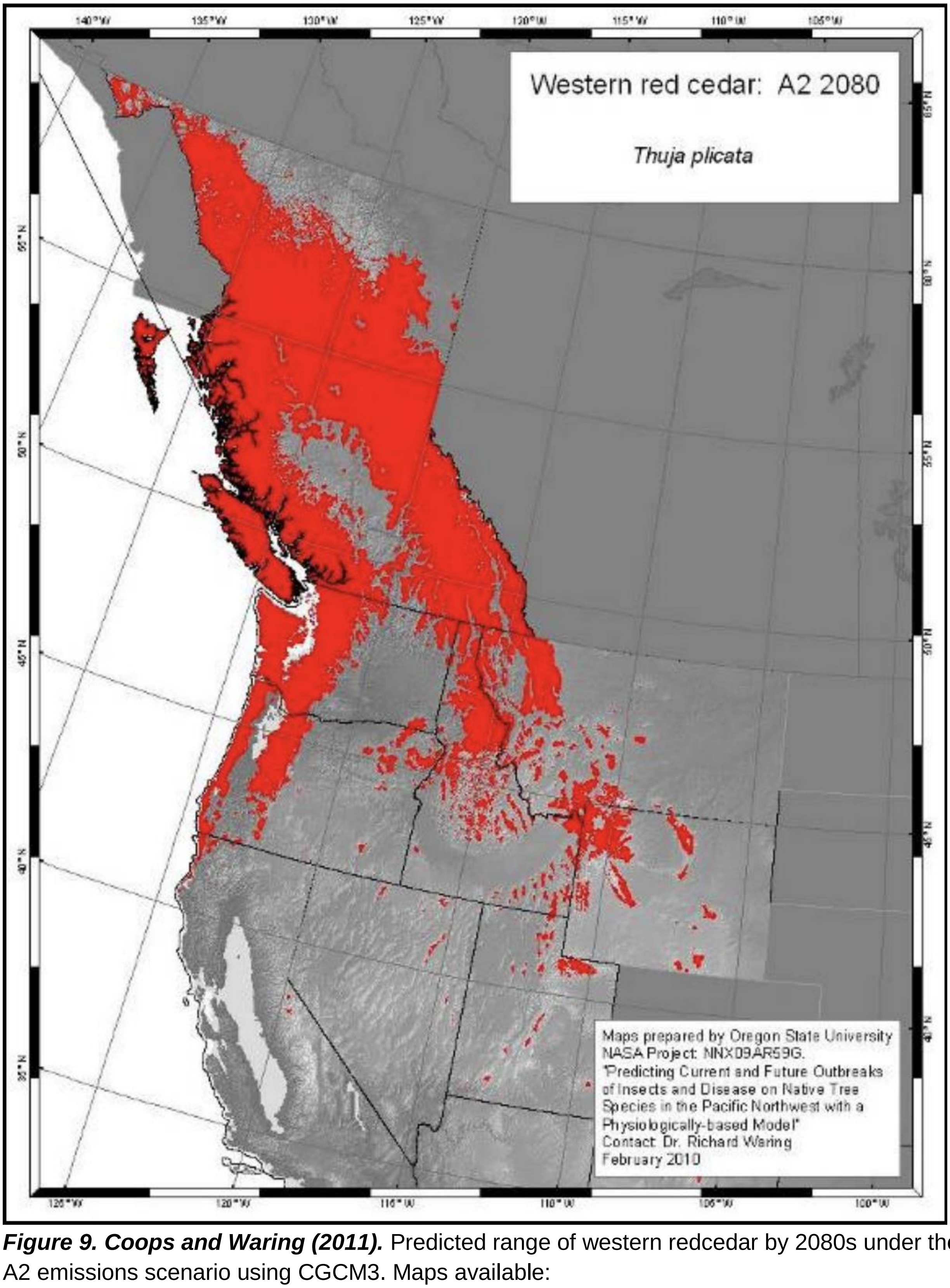

Figure 9. Coops and Waring (2011). Predicted range of western redcedar by 2080s under the A2 emissions scenario using CGCM3. Maps available: http://www.pnwspecieschange.info/linked/westernredcedarresults.pdf

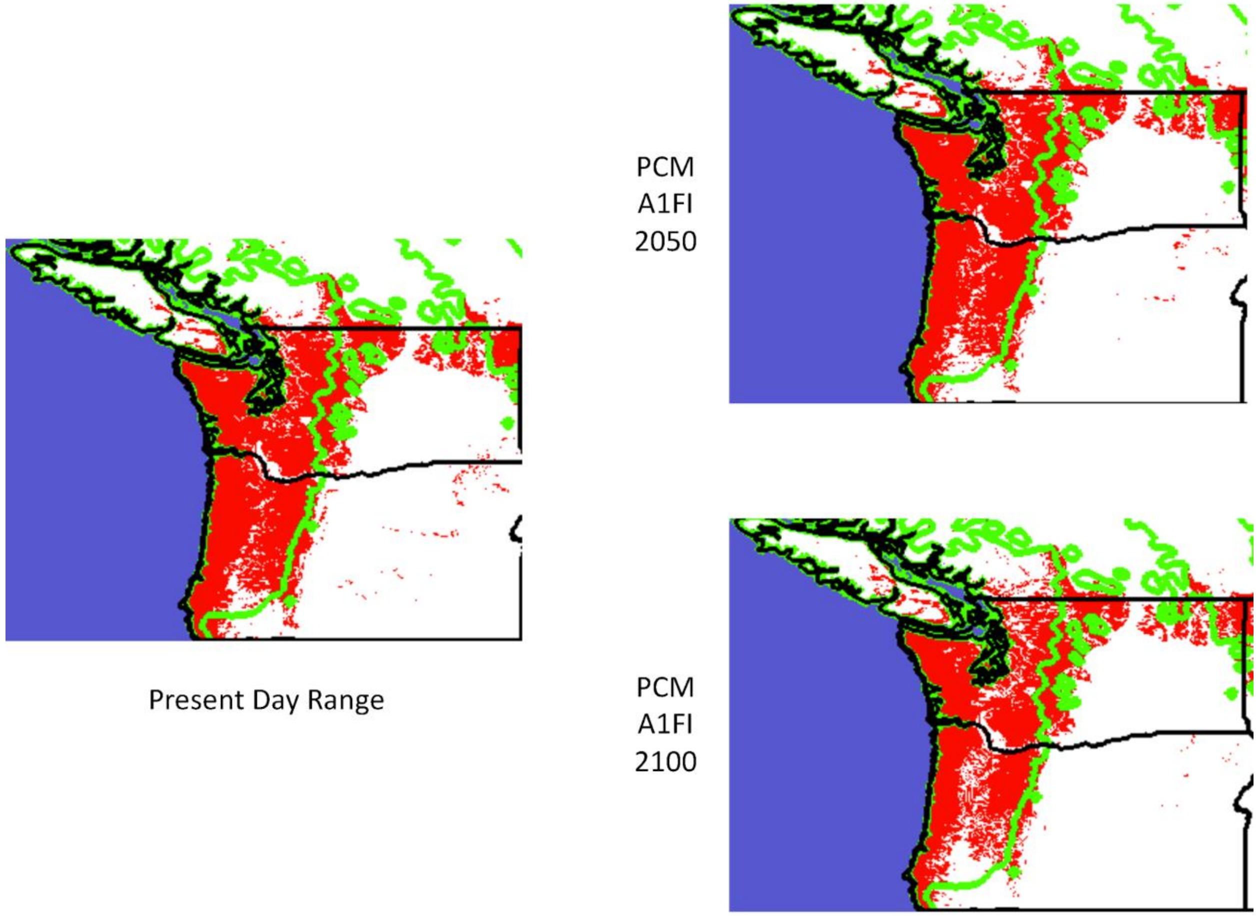

Figure 10. Projections of western redcedar (*Thuja plicata*) climate habitat based on modeled current (left), mid-century (top-right) and end-of-century (bottom-right) climates based on a PCM prediction under the A1F1 emissions scenario. Hargrove and Hoffman (2005). https://www.geobabble.org/ForeCASTS/html/Thuja_plicata_final.elev.html

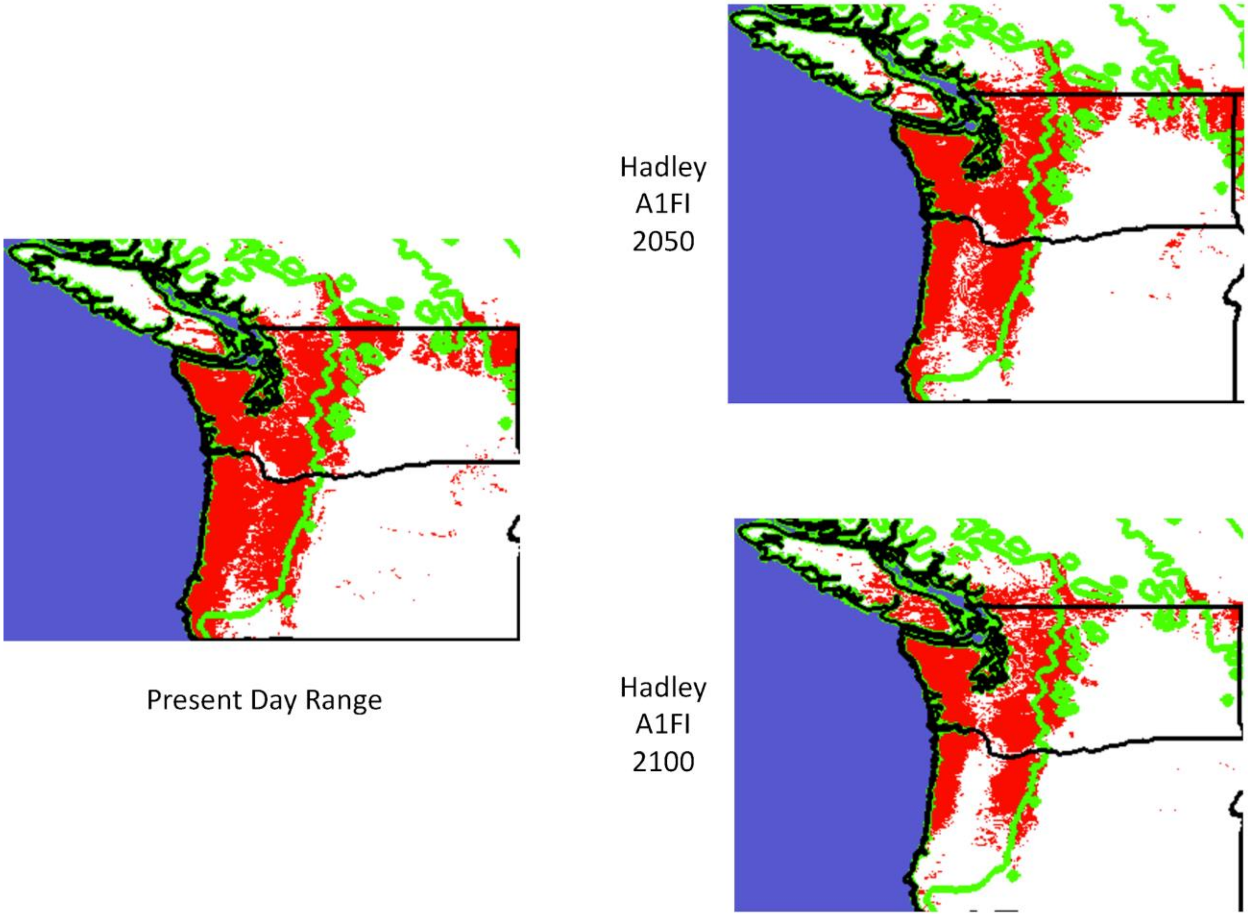

Figure 11. Projections of western redcedar (*Thuja plicata*) climate habitat based on modeled current (left), mid-century (top-right), and end-of-century (bottom-right) climates based on a Hadley prediction under the A1F1 emissions scenario. Hargrove and Hoffman (2005).
https://www.geobabble.org/ForeCASTS/html/Thuja_plicata_final.elev.html

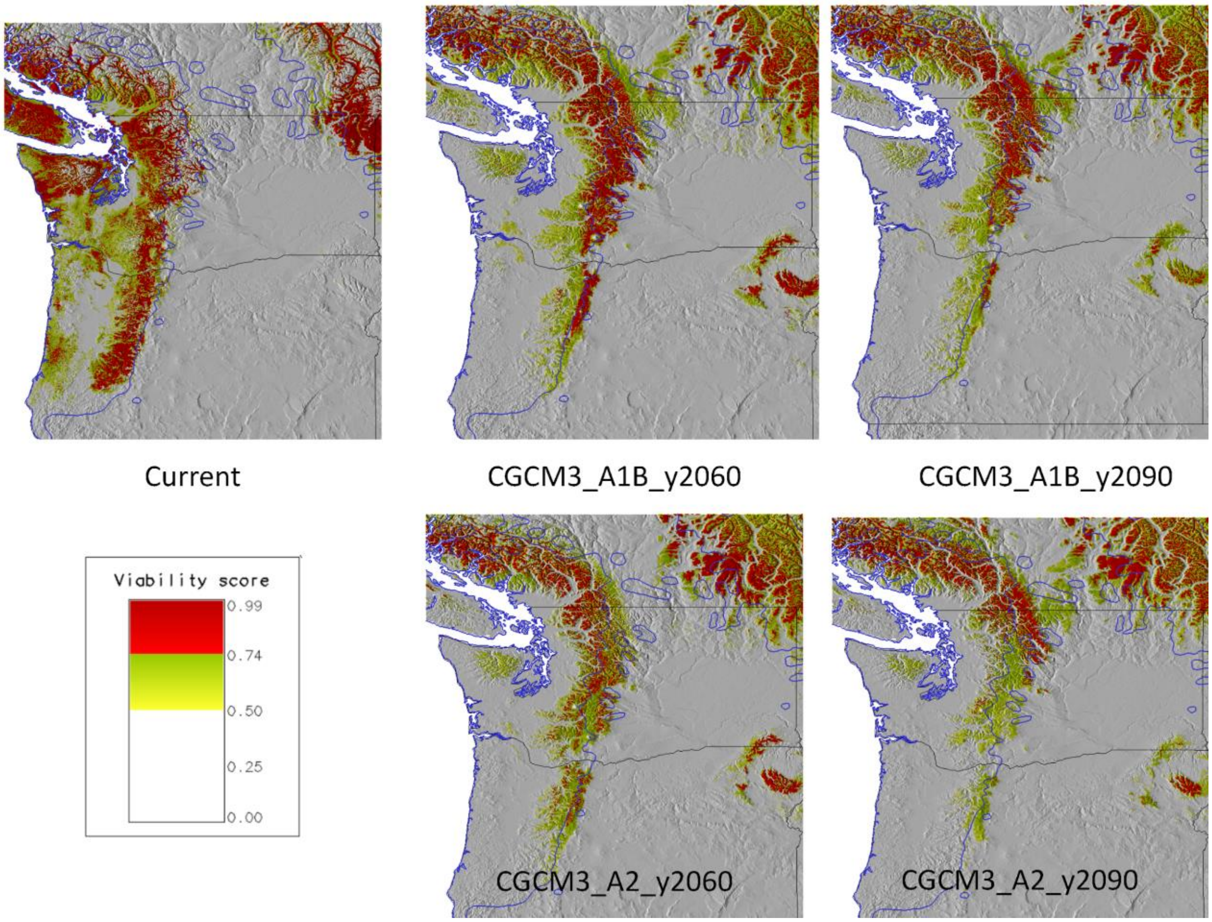

Figure 12. Estimate of the likelihood that the climate will be suitable for western redcedar for the 2060s and 2090s under a medium (A1B) and high (A2) emissions scenario using the CHCM3 GCM. Values reflect species viability scores in the range of 0 to 1, where low numbers indicate that the climate is not consistent with where the species grows and high numbers indicate it is consistent (Crookston et al. 2010). http://charcoal.cnre.vt.edu/climate/species/speciesDist/Western-redcedar/

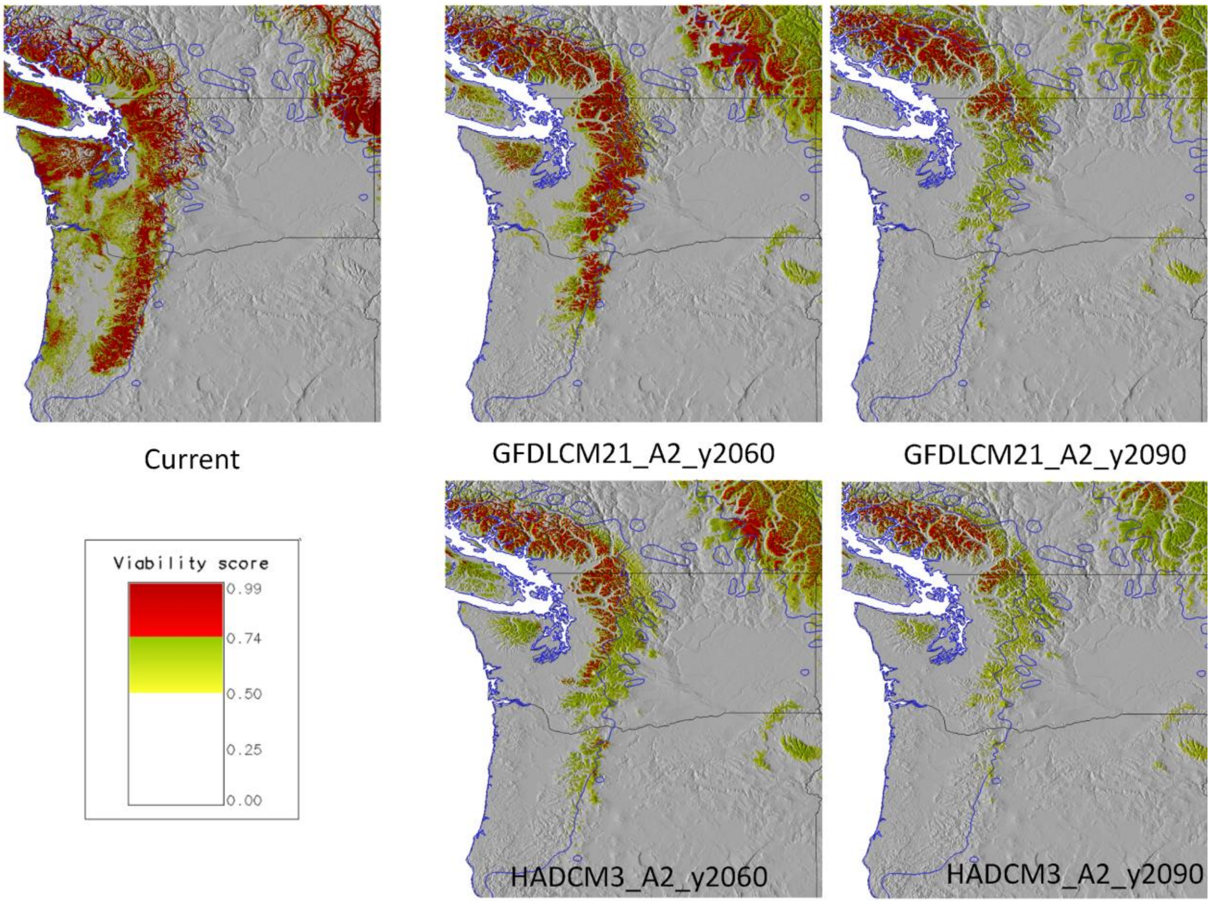

Figure 13. Estimate of the likelihood that the climate is suitable for western redcedar for the 2060s and 2090s under a high (A2) emission scenario using the GFDLCM21 and HADCM3 GCM. Values reflect species viability scores in the range of 0 to 1, where low numbers indicate that the climate is not consistent with where the species grows and high numbers indicate that it is consistent (Crookston et al. 2010).
http://charcoal.cnre.vt.edu/climate/species/speciesDist/Western-redcedar/

Appendix B. Conceptual Model of Climate Impacts on Western Redcedar

We created a conceptual model that summarizes the ecological and climatic drivers of western redcedar 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 western redcedar.

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 western redcedar in western Washington.

Conceptual Model of Climate Impacts on Western Redcedar | x̌payʔac