An Analysis of Climate Change Implications for Culturally Significant Plant in the Tulalip Tribes Treaty Lands

Prepared by the Tulalip Tribes Treaty and Government Affairs Department

with assistance from the University of Washington, Climate Impact Group

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Introduction

In 2018 Tulalip Tribes set out to develop data and tools to help us better understand how extreme events and harmful environmental trends related to climate change would affect specific plant species important to our ongoing management of Treaty reserved resources. We proposed an analysis of vegetation to predict changes to the end of this century so that Tulalip Tribes can develop strategies for management of treaty resources such as fish, wildlife and plants. We intended to engage other tribes throughout the region of the Treaty of Point Elliott of 1855.

Our scope of work included a literature review of vegetation response to environmental change, workshops to engage knowledge keepers and tribal scientists, an assessment of change to species or plant communities identified in the workshops, and development of a decision support tools using the Ecosystem Management Decision Support system developed by the United States Forest Service.

The Covid 19 Pandemic required that we change our approach for this project. Many of the tribes we intended to engage reduced operations for several months. As a result, we decided to focus on Tulalip knowledge keepers and staff for this project. This final report completes Objective 2, Task 5 of our proposal. It summarizes the process, limitations, outcomes and recommendations for future direction of adapting ecosystem management to climate change in our region.

Our Methods

Our project consisted of three primary parts: 1) Interviews with Tribal Elders and Natural Resources staff; 2) Profile of climate change effects to plants based on existing scientific research; and 3) Our assessment of how Tribal resources will be affected and next steps.

We interviewed Elders from Tulalip Tribes to learn about their concerns about how climate change will affect plants that they collect. We also interviewed Tulalip Natural Resources Department staff to learn their concerns about how climate change will affect management responsibilities. From these interviews we developed a list of candidate species upon which to focus. We selected one plant community and five species to profile. We chose the plant community because it is the most widespread in our region. The plant species represent a wide range of habitat types, from lowland camas prairies to subalpine huckleberry fields.

With the information from our Elders and staff we asked ecologists at the Climate Impact Group (CIG) at the University of Washington (UW) to review the scientific literature relating to the effects of climate change on plants. They summarized the findings of dozens of scientific papers. Then they developed models showing how social and environmental factors will interact with climate change to affect our selected plant community and the five species.

Lastly, we used information generated from a parallel study modeling forest management scenarios for water retention the Snohomish Watershed. In that project we used PA's VELMA ecohydrology simulation system, that takes air temperature and precipitation as input and simulates biomass growth and surface and sub-surface hydrology. Early results highlight the complex interaction between precipitation patterns, air temperature soils and surface and sub-surface water in determining soil moisture, a key landscape condition for vegetation (see the Section Landscape of the future). In addition, VELMA provides snow depth spatial distributions and timing that matter for those species that require protection from frost.

Environmental Effects of Climate Change in Our Area

In 2015 the Climate Impact Group at the University of Washington published a "State of Knowledge" report for climate change around Puget Sound. At this time, seven years later, that report is still considered an accurate picture of the predicted effects of climate change[1]. There are several sections in the UW-CIG report with descriptions of how climate change will affect resources important to Tulalip Tribes. The region addressed in the report is the southern portion of the Salish Sea including the Strait of Juan de Fuca. Rather than summarize the scientific literature on the subject again, we have excerpted portions of that report verbatim. However, we only included portions that we thought relevant to the effort reported in this document. The report can be found at our on-line climate change library at https://nr.tulaliptribes.com/Topics/ClimateChange/ClimateChangeReferenceLibrary, or at the Climate Impact Group's website at https://cig.uw.edu/resources/special-reports/ps-sok/.

For maps of quantitative projections of trends in landscape scale conditions due to climate change – e.g., Air Temperature, Snowpack, Soil Moisture, see the Section "The Landscape of the Future" below.

The italicized paragraphs below are from the 2015 UW-CIG Puget Sound climate report. Emphasis is ours. We refer the reader to the original document for footnotes and references.

Terrestrial Ecosystems

> *Terrestrial ecosystems in the Puget Sound region are projected to experience a continued* ***shift in the geographic distribution of species, changes forest growth and productivity, increasing fire activity, and changing risks from insects, diseases, and invasive species****. These changes have significant implications for ecosystem composition and species interactions. Changes are projected to be most pronounced at high elevations, where* ***increasing air temperatures and declining snowpack*** *can degrade habitat quality for some species but benefit others via a longer snow-free season and increased biological productivity. Many of the changes expected for Puget Sound forests are likely to be driven by* ***increases in the frequency and intensity of***

[1] Personal communication with Guillaume Mauger, University of Washington Climate Impact Group.

disturbances such as fire, insect outbreaks, and disease.

Climate Drivers of Change
Projected changes in the Puget Sound region's terrestrial environment are driven by increasing air temperature, reduced snow accumulation, and declining summer precipitation.

- *Observations show a clear warming trend, and all scenarios project* ***continued warming during this century****. Most scenarios project that this warming will be outside of the range of historical variations by mid-century (see Section 2). Warming, along with reduced snowpack, will result in a* ***longer growing season*** *and an* ***earlier onset spring growth****.* ***Declining snowpack*** *will also drive a decline in summer water availability, with consequences for soils, streams, and groundwater. Finally, the associated shift to earlier peak streamflow could negatively affect floodplain wetlands.*

- *Most models are consistent in projecting a substantial* ***decline in summer precipitation****. Projected changes in other seasons and for annual precipitation are not consistent among models, and trends are generally much smaller than natural year-to-year variability. Projected decreases in summer precipitation will exacerbate the temperature-induced shift from snow accumulation to rain.*

Changes in Timing of Biological Events
Climate change could alter the timing (or "phenology") of some biological events.
- *A lack of sufficiently cold air temperatures may delay leaf emergence. Studies of Douglas-fir in western Washington and Oregon have found that warmer air temperatures may result in earlier spring growth initiation, but that rising winter air temperatures could lead to delayed leaf emergence due to an unfulfilled winter chill requirement. One study documented irregular leaf timing in plants with a winter chilling requirement (including Douglas-fir) that received no to low levels of chilling.*

Changes in the Geographic Distribution of Species
Climate change is projected to alter species' geographic distributions. Some species may be unable to move fast enough to keep pace with shifting climates, which may result in local extinctions. Both range shifts and local extinctions are likely to lead to changes in the composition of biological communities in the Puget Sound region. Because species will respond individualistically, effects should be considered on a case-by-case basis. For many species, the effects of land-use and fragmentation may act as a more serious stressor than climate change.

- *Garry Oak (Quercus garryana) habitat may increase or decrease. One set of model projections showed a significant contraction of the range of Oregon white oak / Garry oak on the west side of the Cascades and an expansion on the east side of the Cascades by the end of the century. This shift is a result of increasing air temperatures projected west of the Cascades. However, another study found that climate suitability for Garry oak is generally projected to increase across Washington, Oregon, and British Columbia.*

• Increasing air temperatures may result in increased tree growth at high elevations, as well as local tree expansion into subalpine meadows. One study projects that suitable conditions for subalpine and tundra vegetation could decline by the end of the 21st century with warming on the Olympic Peninsula. Montane meadows in the North Cascades may also decrease in extent as reduced snowpack and longer growing seasons allow trees to establish in meadow areas.

• Climate change may lead to prairie expansion in the Puget Sound region. Increases in summer water stress will negatively affect less drought tolerant trees and species adjacent to prairies, potentially enabling prairie ecosystems to expand. Increases in winter precipitation may also lead to an increase in the area of wetland prairies in south Puget Sound. Further research is needed on how exotic prairie species in the Puget Sound region will respond to climate change.

Forests

Climate change is projected to affect the distribution and productivity of Puget Sound forests. Changes are driven by increasing air temperatures, reductions in snowpack, and declining summer water availability.

• The geographic distribution of forests is projected to change. Increasing air temperatures and drier summer conditions are likely to reduce the area of climatically suitable habitat for Douglas-fir in lower elevations of the Puget Sound region, specifically in the south Puget Sound and southern Olympic Mountains, by the end of the 2060s. Across the entire Pacific Northwest, western hemlock, whitebark pine, and western redcedar may expand their ranges under climate change by the end of the century.

• Declining snowpack is projected to result in increased growth. In the high elevations of the Olympic and Cascade ranges, tree establishment and growth is limited by the amount of snowpack and the duration of the snow season. Increasing air temperatures will result in lower snowpack levels and earlier snowmelt. This will allow for an earlier start to the growing season and increased productivity in high elevation forests.

• Decreased water availability will cause further summer water stress. Forests that are currently water stressed in summer are likely to experience more severe or longer duration water stress in the future. Increased water stress is likely to result in decreased tree growth and declining forest productivity, in particular for the northeastern forests of the Olympic Peninsula. These declines in water availability will decrease fuel moisture, and will likely increase fire risk in these forests, which in turn, could increase susceptibility to pine beetle outbreaks.

Wildfire

Climate change is expected to increase fire activity in the Puget Sound region, even though the area is not thought to have been fire prone historically. Increasing air temperatures and drier conditions are the primary mechanisms leading to projected increases in area burned for Washington State.

• Past fires have been large but rare in the Puget Sound region. Fire history west of the Cascades is defined by infrequent, large, stand-replacing fires occurring every 200 to 500 years. There were three major burning episodes on the Olympic Peninsula during the Little Ice Age (1300-1750), the last of which occurred between 313 and 346 years ago. This fire (or multiple fires) burned more than one million acres on the Olympic Peninsula, and between three and ten million acres in western Washington. On the Olympic Peninsula, fires are more frequent among the drier western hemlock, subalpine fir, and Douglas fir forests on the eastern side of the peninsula.

• Area burned is projected to increase. Two different studies estimate that the annual area burned for Northwest forests west of the Cascade crest could more than double, on average, by 2070-2099 compared to 1971-2000. However, the models used to project fire risk west of the Cascades are limited in their ability to capture the rare combination of conditions associated with wildfires in the region. Further research is needed to clarify the mechanisms of changing fire risk and severity in the Puget Sound region.

Projected increases in wildfires in the western Cascades may negatively affect the ability of terrestrial ecosystems to store carbon. It is not known if increased ecosystem productivity resulting from longer growing seasons and increased carbon dioxide (CO2) concentrations will offset carbon losses from wildfires.

• Carbon storage is projected to decline. Fire risk is projected to increase for the maritime forests west of the Cascades. These forests could possibly lose up to –46% of ecosystem carbon stocks (1.2 billion metric tons of carbon) by the end of the century. Fire suppression was incorporated in model simulations but was shown to be unable to mitigate these fire-induced carbon emissions. Another study projects that by the 2040s the mean live biomass (Mg C/ha) in the western Cascades will decrease by –24% to –37% by the 2040s (2030-2059).

Insects and Disease

Insect and disease outbreaks are projected to change in prevalence and location, as forests become more susceptible due to climate stressors (e.g., increasing water stress), and areas climatically suitable for outbreaks shift. However, making generalizations about how pathogens will respond to climate change is difficult because responses are likely to be species- and host-specific.

• Some diseases and pathogens could become more prevalent, while others may not. Projected increases in air temperature and declines in summer water availability will likely decrease the effect of sudden oak death, Dothistroma needle blight, Swiss needle cast (Figure 9-2), and white pine blister rust on forest communities in the Puget Sound region. Some tree species affected by these forest diseases include Douglas-fir, Pacific madrone, and white pine. Conversely, warming and declines in summer water availability will likely increase the impact that Armillaria root disease and some canker pathogens have on forest communities in the Puget Sound region. Armillaria root disease and canker pathogens affect conifer and hardwood trees in the Puget Sound region.

• *Bark beetles are projected to become less prevalent in the Cascade and Olympic ranges. While current air temperatures in areas of the Olympic Mountains and western white pine forests of the Cascade Mountains are suitable for bark beetles, modeled results suggest that increasing air temperatures may lead to shifts in the areas of suitability for bark beetles to higher elevation forests in the Cascade and Olympic ranges.*

Effect of Climate Change on Tulalip Tribes

From time immemorial the Coast Salish people, including the Tulalip Tribes, maintained a high level of biodiversity in a wide variety of healthy and sustainable ecosystems through a reciprocal relationship with the land and its inhabitants. The people cultivated the landscape to provide productive habitat for the plants, fish and wildlife, while in turn these inhabitants of the land were available to sustain the people. When Euro-American colonizers arrived the lifeways of the people were forcibly stopped and a different relationship with the land was imposed. One which maximized the short-term gain of individuals, often without concern of future sustainability of the “resources” being harvested. In the time since the Treaty of Point Elliott was signed the land has been degraded and resources reduced. Over the past several decades Tulalip Tribes has been working with the United States and the State of Washington to restore these ecosystem-based resources. Climate change is an additional complication for resource restoration.

Many species of plants that are important to Tulalip have ranges that extend well north and south of our traditional lands. Some of these species may lose suitable habitat on the southern end of this range as changes to precipitation and temperature make these areas to hot and dry to be suitable habitat. Conversely, the range may extend further north as habitat opens up due to more suitable precipitation and temperature there. Tulalip lands are well within what will remain of the suitable range for many species beyond the turn of this century.

However, the greatest vulnerability for local species may be due to changes in the climate on an elevational gradient. High elevation species will find habitat diminishing as the snow season contracts and the summer drought extends in time. A suitable climate for these species will move up in elevation off the ridgetops and peaks. Species in the elevations that are currently subalpine will migrate upslope, but will find more competition at current locations as these elevations become suitable habitat for species that are currently mid-elevation plants.

Species at lower elevations are also predicted to lose suitable habitat due to extended summer drought. Even in locations with sufficient ground water to supply plants during drought conditions, excess heat may cause rates of evapotranspiration to exceed the physiological capabilities of the plants. Anecdotal evidence suggests that western redcedar may not tolerate high temperatures because of limits in its ability to control transpiration. Tulalip Forestry Department staff have observed more stressed, dying and dead western redcedar on the reservation in recent years (the cause has not been investigated). Some modeling results predict that Douglas fir will also be subject to drought stress in lower elevations, but may occupy newly suitable habitat at higher elevations, as noted in our climate summary above. Our coastal zones may lose populations of Douglas fir over the next several decades (Figure 1) because of increased summer drought.

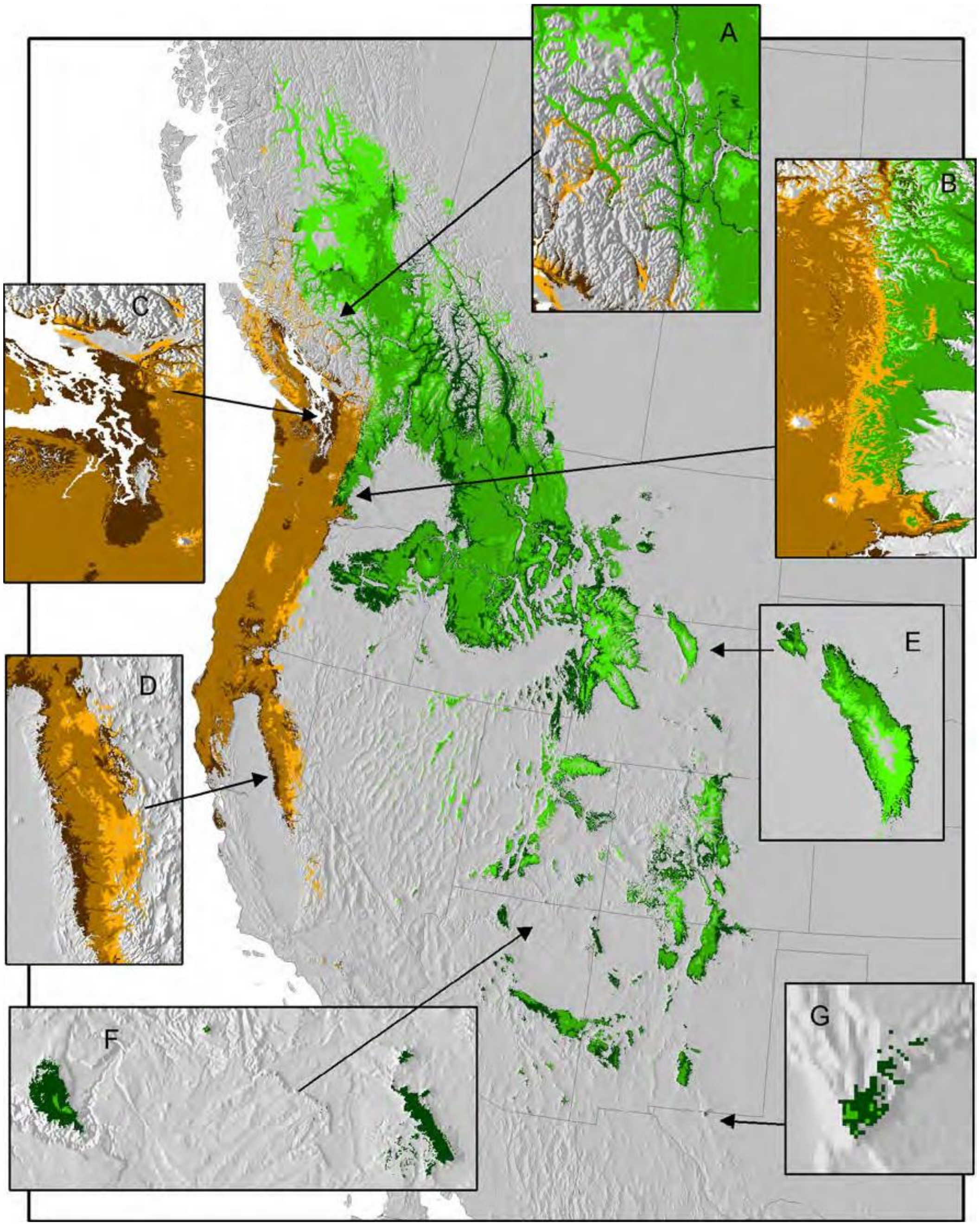

Figure 1. Impact of climate change projected for *Pseudotsugs menziesii* var. *menziesii* (brown colorpath) and var. *glauca* (green colorpath) north of Mexico. Darkest tones color grid cells present in the contemporary climate niche but lost in 2060 niche space; middle tones color grid cells expected to be within the climate niche at both time periods; and brightest tones color grid cells expected to be added to the niche in 2060. Panels zoom in on locations discussed in detail[2].

[2]Excerpt from Rehfeldt, et al. 2014. Comparative genetic responses to climate for the varieties of *Pinus ponderosa* and *Pseudotsuga Menseisii*: Realized climate niches. Forest Ecology and Mangement, 324: 126-137. http://dx.doi.org/10.1016/j.foreco.2014.02.035

Interviews

The specific information provided in the interviews with Elders is the intellectual property of each person so is not described in this public document. We refer here only to general concepts. However, the information of the Elders will be used as the Tulalip Tribes moves forward as we adapt our natural resource management strategies to climate change. Interviews were conducted by young Tribal citizens employed by the Natural Resources Department. In this way we are ensuring that the intellectual property of the Elders interviewed stays in the Tribes.

Elders said that they have observed changes in the seasons that have affected harvest timing and plant health. Some plants don't reliably grow in the same places, so that greater travel is required for harvesting. Some plants show obvious signs of stress, so harvest is avoided. Elders mentioned that lack of Indian burning as a tool for managing the land has changed the landscape in ways that make it less productive.

Tulalip Natural Resource Department staff were also interviewed. Information relating to plant species use is also the intellectual property of the Tulalip Tribes for whom these staff work, and so is not included here. More general information about observations by Elders and staff is summarized. Many of the Tulalip Tribes Natural Resources staff interviewed for this project have a good number of years working for Tulalip. Most staff indicated that they have not noticed too much change in the landscape until recently with long-term droughts, such as that experience in 2012 and 2015. Some staff have noticed an increase of invasive species on the landscape beginning in the 90s or early 2000s—becoming more prevalent over time. In particular, Natural Resources staff have noticed an increase of invasive species in estuaries and floodplains, as well as in disturbed forests.

A prominent topic brought up in a majority of staff interviews was that of tribal fire activity on the landscape. Traditional fire activity is a cross-cutting practice of land stewardship that benefits a number of ecological functions. Staff brought up that prescribed burns promote habitat for ungulates, as well as help sustain plant species that rely on fire activity—such as huckleberry. In addition, prescribed burns mitigate wildfire through removing fuel storage across the landscape.

Another topic mentioned in regards to mitigating wildfire included managing our landscapes to keep native vegetation. Through keeping native vegetation, invasive species will be kept more in check, negating their negative impact to ecological functions, as well as reduce fuel sources on the edges of developments and disturbed areas. This management of keeping native vegetation will also reduce the chances of Tribes' members to deal with wildfire and smoke in our areas of interests, while promoting physical and mental health.

Related, a majority of staff highlighted the need to allow for longer rotations of timber. Natural Resources staff indicated that emerging science shows that longer standing tree stands take less water than shorter rotation tree stands. Therefore, it will be important to manage for longer rotations as the region expects extended summer drought to extend the season of low-flows in streams and rivers. This also connects wildfire mitigation and the need to connect with private timber managers on these issues. There is a similar staff concern around how the state and local agencies are not prepared for climate change in the highlands—in particular around rivers and streams. More prepared and better management of upland forests along rivers would help mitigate water flow and temperature for salmon.

Staff highlighted the long importance of timber to the Tulalip Tribes following the Point Elliott Treaty of 1855. Douglas fir are important fuel sources for Tribes members at home and culturally. Understanding how climate change will impact Douglas-Fir will be important for Tribes members and Tulalip Forestry. In addition, Tulalip Forestry has asked when they need to begin planting drier-tolerant trees that will be up for timber harvest decades from today. It is indicated by staff that timber land, tribally, state or privately owned, can be managed more traditionally for wildlife and treaty reserved resources. As Tulalip ancestors have always managed working forests.

Tulalip Natural Resources staff indicated that Tribes members say that plants, animals, and fish are less abundant than 50 years ago. Our tribal membership will continue to grow with the generations and we will need to take the opportunity to grow our protection and access to treaty resources. Staff indicated that this will require pressuring our federal trustees to work with Tulalip to protect species negatively affected by climate change trends. Federal trustees need to listen to Treaty Tribes and meet the standards and scale set by Treaty Tribes and manage for the Treaty Tribes' value on the landscape. Not to let lands be managed by a third party or cater a different management that is opposite to Treaty Tribes' standards and scale for wildlife and culture.

Profiles for Selected Treaty Resources

In place of providing information from Elders about species they shared we chose to provide profiles describing how climate will affect the most extensive plant community in our region, along with five species that are broadly known as food or medicinal plants among the greater non-indigenous Salish Sea population (Table 1). In this document we share the climate implications for these species but not traditional uses or gathering locations, which is the intellectual property of Tulalip Tribes.

We asked UW-CIG to review the scientific literature to create climate profiles and models of the social and environmental factors driving the effect on the selected plant community and five species.

Table 1. Five widely used plant species and the most extensive plant community in the Salish Sea region.

Lushootseed Name	Local Common Name(s)	Scientific Name
t̓əq̓ədiʔac	Western Hemlock Zone	N/A
qʷəlut	Indian tea or Labrador tea	*Rhododendron groenlandicum*
swədaʔx̌	Big huckleberry	*Vaccinium membranaceum*
gʷədbixʷ	Trailing blackberry	*Rubus ursinus*
qʷəɬuʔəl	Common Camas	*Camassia quamash*
x̌payʔac	Western redcedar	*Thuja plicata*

Below are excerpts from the UW-CIG climate profiles for each species. More information can be found in the complete profiles, including a list of references used to compile these profiles is included as an appendix to this document.

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.

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, which result in closed leaf stomata that restrict water loss and limit carbon dioxide uptake.

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.

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).

- *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.

Labrador Tea | qʷəlut

Labrador tea (*Rhododendron groenlandicum*), also known as bog Labrador tea or rusty Labrador tea, is a widespread, slow-growing evergreen shrub, typically found west of the Cascades in swamps and bogs at low- to mid-elevations. Feather mosses are frequently found in the understory. Labrador tea produces a large number of small, wind-dispersed seeds (>50 seeds per flower), suggesting it is able to generate a significant seed crop most years (Gucker 2006).

Future changes in climate may present challenges for Labrador tea. Warming air temperatures, earlier snowmelt, declining soil moisture and lower water levels in wetlands and bogs could reduce habitat suitability for the Labrador tea.

Synthesis & Key Conclusions

- Projected reductions in soil moisture and water availability suggest that Labrador tea is likely to be negatively affected by future hydrologic changes in the Northwest.
- For Labrador tea growing in swamps and bogs at mid-elevations, projected declines in winter snowpack and advances in spring snowpack melt are likely to negatively affect Labrador tea due to reductions in moisture availability during dry summer months.

Opportunities and Considerations for Applying Results

- *Supporting Climate Adaptation:* While results of available spatial models are too coarse to be used to identify specific swamps or bogs to prioritize for adaptation actions supporting Labrador tea, they are nonetheless useful for understanding how and where (more generally) the species may be affected by changing climatic conditions. For example, model results suggest that management actions aimed at maintaining the hydroperiod and water supply for bogs and wetlands where Labrador tea is found may help support populations under drier future conditions.
- *Identify future research needs*: Limitations of existing models suggest that future research is needed to create higher resolution spatial models of projected changes in climatic variables relevant to Labrador tea, or, preferably, climatic niche models or mechanistic models that predict future areas of Labrador tea suitable habitat within the area of interest. Such models would be useful in identifying and prioritizing specific bogs and swamps for active management, restoration and protection of Labrador tea.
- *Integration with local knowledge:* Application of results will be most effective if combined with the local knowledge and expertise of Tribal scientists and knowledge keepers. For example, knowledge of the location of Labrador tea populations in swamps or bogs that may be more resilient to climate change due to micro-climatic conditions that may help maintain hydroperiod could be used to prioritize those habitats for protection or restoration.

Big Huckleberry | swədaʔx̌

Big huckleberry (*Vaccinium membranaceum*; hereafter 'huckleberry'), also known as thinleaf, mountain, or black huckleberry, occurs throughout subalpine regions of the Pacific Northwest. In the Washington Cascades, huckleberry is found in dry subalpine zones and often grows with beargrass. It is a dominant species in both fir and hemlock forests in the western Cascades, and occurs in the understory of Pacific silver fir, noble fir, mountain hemlock, Douglas-fir, western white pine and western redcedar. Huckleberry is *c*urrently found from ~3,000 ft. to the higher elevations of the Cascades Range.

Prior to European settlement, Native peoples west of the Cascades used fire as a tool to improve huckleberry habitat by removing conifers encroaching on meadows. Huckleberry is typically able to survive low to moderate severity fires and is adapted to resprout from rhizomes after low to moderately severe fires. Current forest practices in the Pacific Northwest, including fire suppression policies and localized declines in logging coinciding with the designation of late successional reserves, are likely connected to the declining area of suitable huckleberry habitat and declines in huckleberry productivity.

Synthesis & Key Conclusions

- Climate change is projected to reduce habitat suitability for huckleberry in the Northwest, and is likely to cause areas of huckleberry habitat to contract across the geography of the Treaty of Point Elliott. Specifically, huckleberry distributions may shift to higher elevations, where more suitable climatic conditions may be available under future scenarios.
- Models also predict that huckleberry flowering and fruiting will advance in timing by the end of the 21st century, moving earlier in the year. Vulnerability of frost damage will likely increase as flowering dates advance, which may damage huckleberry flowers and result in years with no fruit crop.
- Warming spring temperatures may negatively affect future huckleberry productivity, but additional research is needed in this area.

Opportunities and Considerations for Applying Results

- Results from the Prevey et al. (2020) study, which project changes in huckleberry habitat suitability and berry phenology across the Northwest, can be used for planning, management, and restoration efforts of huckleberry across the region. Anticipating these projected changes provides an opportunity to shift natural resource management strategies and policies. Results could be used by natural resource managers to determine priorities for competing projects, and identify (generally) where new areas may be suitable for huckleberry patches.
- Future work should evaluate how the projected shifts in habitat suitability and phenology of big huckleberry could have cascading impacts to pollinators, animals, and human communities -- who all rely on huckleberries for different resources.

- Application of results will be most effective if combined with the local knowledge of Tribal scientists and knowledge keepers. For example, knowledge of the location of huckleberry habitat that may be more resilient to climate change due to being located in higher elevations with cooler temperatures could be used to prioritize those habitats for protection or restoration.
- Reduce existing stressors. Because climate change is one of many stressors affecting natural systems, reducing non-climate stressors (e.g., invasive species, habitat loss, overharvesting) can help to increase resilience to climate change. Although the benefits of reducing non-climate stressors are generally well established, the degree to which reducing non-climate stresses increases system resilience may depend on the specific nature of the climate impact(s).
- To understand how specific changes may be occurring across the Treaty of Point Elliot area, monitoring - of phenological shifts in flowering and fruiting timing, possible resulting mismatches between huckleberry flowering and pollinator presence, and possible conifer encroachment into huckleberry patches - may be particularly useful for informing future decisions.
- Managing big huckleberry in a changing climate management approach will require some active strategies such removing trees that are encroaching into huckleberry habitat and using prescribed fire to kill encroaching thin-barked trees and encourage the development of new, more rigorous sprouts from huckleberry rhizomes.

Trailing Blackberry | gʷədbixʷ

Trailing blackberry (*Rubus ursinus*), also known as Pacific blackberry, California blackberry or Douglasberry, is a native, perennial, trailing shrub growing from northern California to British Columbia. It is particularly abundant between the Pacific Coast and the Cascade Range, and is found in a variety of plant communities throughout its range.

No studies have yet evaluated the observed or projected impacts of climate change on native blackberries. Here, we describe ecological and climatic processes and conditions that influence the abundance of trailing blackberry in western Washington in an effort to infer how it may respond to future changes in climate.

Ecological and Climatic Drivers

- **Summer Drought Stress**
  Once established, trailing blackberry is a drought-tolerant species. However, water stress can negatively affect blackberry fruit yield. Summer water deficit[3] across the Puget Sound lowlands is projected to increase throughout the 21st century; while this may not negatively affect established plants, it may result in lower fruit production.

- **Disturbance**
  Trailing blackberry quickly establishes following disturbances (e.g., wildfire, logging) and is able to outcompete conifer seedlings; it is often one of the dominant species on recently logged or burned forests. While wildfire is relatively infrequent in western Washington forests compared to the eastside, hotter, drier summer conditions are expected to increase the potential for wildfires in this region. This increasing wildfire risk may provide additional post-fire establishment opportunities for trailing blackberry.

- **Invasive Species**
  Himalayan blackberry (*Rubus armeniacus*) and evergreen blackberry (*Rubus laciniatus*) are invasive, non-native blackberry species that grow into dense thickets and produce large fruits (King County Noxious Weeds). These invasive species are difficult to control, quickly overtaking recently disturbed sites and frequently outcompeting trailing blackberry. Increased rates of disturbance (e.g., fire) from climate change may provide additional opportunity for establishment of Himalayan and evergreen blackberries. Further, when herbicides are used to control their spread, the chemicals employed can make trailing blackberry fruits inedible or toxic.

Synthesis and Key Conclusions

- While trailing blackberry is drought tolerant following establishment, water stress can negatively affect fruit yield. Projected increases in summer water deficit may thus result in lower fruit production.

[3] Amount of soil moisture available relative to atmospheric demand for water via evaporation, either from water bodies or vegetation.

- Increasing wildfire on the westside may benefit trailing blackberry, which readily establishes following disturbance.
- Himalayan and evergreen blackberry may benefit from climate-driven disturbances and can outcompete the native trailing blackberry; application of herbicide to control these invasive blackberries can contaminate trailing blackberry fruit growing in adjacent areas.

Opportunities and Considerations for Applying Results

- *Identify future research needs*: To date, no studies have evaluated the potential impacts of climate change on trailing blackberry or trailing blackberry habitat. Research is needed to create higher resolution spatial models of projected changes in climatic variables relevant to trailing blackberry.
- *Integration with local knowledge:* Application of results will be most effective if combined with the local knowledge and expertise of Tribal scientists and knowledge keepers. For example, knowledge of the location of trailing blackberry populations that have fruited well through times of regional water stress, or have not been out-competed by invasive blackberry species could be used to prioritize those habitats for protection or restoration.

Use of traditional practices: Traditional management practices, including the use of prescribed burns, could be used to create opportunities for trailing blackberry establishment. However, close monitoring will be needed to prevent establishment of invasive blackberries.

Common Camas | qʷəɬuʔəl

Camas (*Camassia quamash*), also known as small camas or blue camas, is a perennial forb found in open habitats with seasonally-wet soils that often dry out by spring. In Washington, it ranges from the foothills to mid-elevations on both sides of the Cascades Range.

Throughout the Pacific Northwest, open prairie habitats were maintained by Indigenous communities through the use of fire. However, Euro American colonization brought an end to low-intensity, high-frequency traditional burning practices and a subsequent decline in prairie habit due to tree and shrub encroachment (Hamman et al. 2011). In addition to clearing encroaching vegetation, traditional burning practices also enhanced camas grounds by adding potassium back into the soil (Thoms 1989).

Future changes in climate, including increasing summer temperatures and declines in summer precipitation, could reduce habitat suitability for camas.

Synthesis & Key Conclusions

- Projected decline in summer soil moisture and increase in summer temperatures are likely to negatively affect camas.
- Dynamic global vegetation model results do not project a change in grasslands or savannas west of the Cascades, which bodes well for camas. Further, projected increases in wildfire west of the Cascades may lead to an increase in prairie cover west of the Cascades, though perhaps not before end of century.

Opportunities and Considerations for Applying Results

- *Supporting Climate Adaptation:* Results from studies evaluating the effects of temperature and precipitation on camas growth and productivity are useful for understanding, in a general sense, how and where the species may be affected by changing climatic conditions. For example, correlations between climatic metrics and camas productivity and growth suggest camas may be more likely to persist in wetlands with microclimates more resilient to projected changes; management responses could thus include prioritizing protection or restoration of wetlands likely to remain moist through spring, and/or those that are partially shaded and likely to maintain cooler temperatures than unshaded sites. Results also suggest that management actions aimed at maintaining the hydroperiod and water supply for wetlands where camas is found may help support populations under drier future conditions.
- *Identify future research needs*: Limitations of existing models suggest future research is needed to create higher resolution spatial models of projected changes in climatic variables relevant to common camas, or, preferably, climatic niche models or mechanistic models that predict future areas of suitable habitat for camas within the area of interest. Such models would be useful in identifying and prioritizing specific prairies or wetlands for active management, restoration and protection.

- *Integration with local knowledge:* Application of results will be most effective if combined with the local knowledge and expertise of Tribal scientists and knowledge keepers. For example, knowledge of the location of camas populations in prairies or wetlands that may be more resilient to climate change due to cooler, wetter microclimatic conditions could inform actions promoting their protection or restoration.

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.

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.

The Landscape of the Future

In this section we highlight what the future landscape will look like under climate change, focusing on those changes in conditions that impact our six example treaty resources – the Western Hemlock Zone plant community and five selected species. Treaty Resource Managers may find these spatial descriptions of projected changes in landscape conditions helpful in thinking of pressures that other treaty resource may face through the end of the century.

All Maps are from the 2018 Climate Tribal Tool (https://cig.uw.edu/resources/tribal-vulnerability-assessment-resources/tribal-climate-tool/)[4], as are all climate statistics included in these discussions. Values projected by the Climate tool are calculated for our region from data generated by 20 climate models. Where possible and relevant, we'll include the mid-century (2040-2069) and late century (2070-2099) maps. Unless otherwise noted, maps shown below are based on the high emissions RCP 8.5 Climate Change Scenario.

RCP stands for Representative Concentration Pathways[5] and describe future scenarios that may result from assumed trends in human behavior. They make assumptions about how we might arrive in these futures – we continue to burn fossil fuels at ever increasing rates - and likely consequences, a 3.7ºC average increase in global air temperature by the end of the century[6]. RCP 8.5 is at the highest end of the Representative Concentration Pathways and assumes no mitigation actions – so is often called the "business-as-usual" scenario. Many climate change scientists argue that it is unrealistic, with internal contradictions in its assumptions[7], but others argue that historic data and the slow progress in implementing policies tackling climate change means that RCP 8.5 best represents the worlds current trajectory[8]. Recent data, as shown in Figure 2, suggests that globally, in spite of a minor reduction in 2020 associated with the COVD 19 pandemic, CO^2 emissions are not diminishing, so an assumption of RCP 8.5 seems reasonable for the foreseeable future. In keeping with the precautionary principle, we will use this scenario below. (The Tribal Climate Tool also includes many projection maps for RCP 4.5, a more "middle of the road" scenario that assumes significant climate change mitigation.)

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[4] Krosby, M., Hegewisch, K.C., Norheim, R., Mauger, G., Yazzie,K., H. Morgan. 2018."Tribal Climate Tool" web tool. Climate Impacts Group(https://cig.uw.edu/resources/tribal-vulnerability-assessment-resources/) and Climate Toolbox (https://climatetoolbox.org/) accessed on [date figure downloaded].

[5] van Vuuren, D.P., Edmonds, J., Kainuma, M. *et al.* The representative concentration pathways: an overview. *Climatic Change* **109,** 5 (2011). https://doi.org/10.1007/s10584-011-0148-z

[6] What are the RCPs? https://coastadapt.com.au/sites/default/files/infographics/15-117-NCCARFINFOGRAPHICS-01-UPLOADED-WEB%2827Feb%29.pdf

[7] Hausfather, Z.; Peters, G. P. Emissions – the 'Business as Usual' Story Is Misleading. Nature 2020, 577 (7792), 618–620. https://doi.org/10.1038/d41586-020-00177-3.

[8] Schwalm, C. R.; Glendon, S.; Duffy, P. B. RCP8.5 Tracks Cumulative CO2 Emissions. Proceedings of the National Academy of Sciences 2020, 117 (33), 19656–19657. https://doi.org/10.1073/pnas.2007117117.

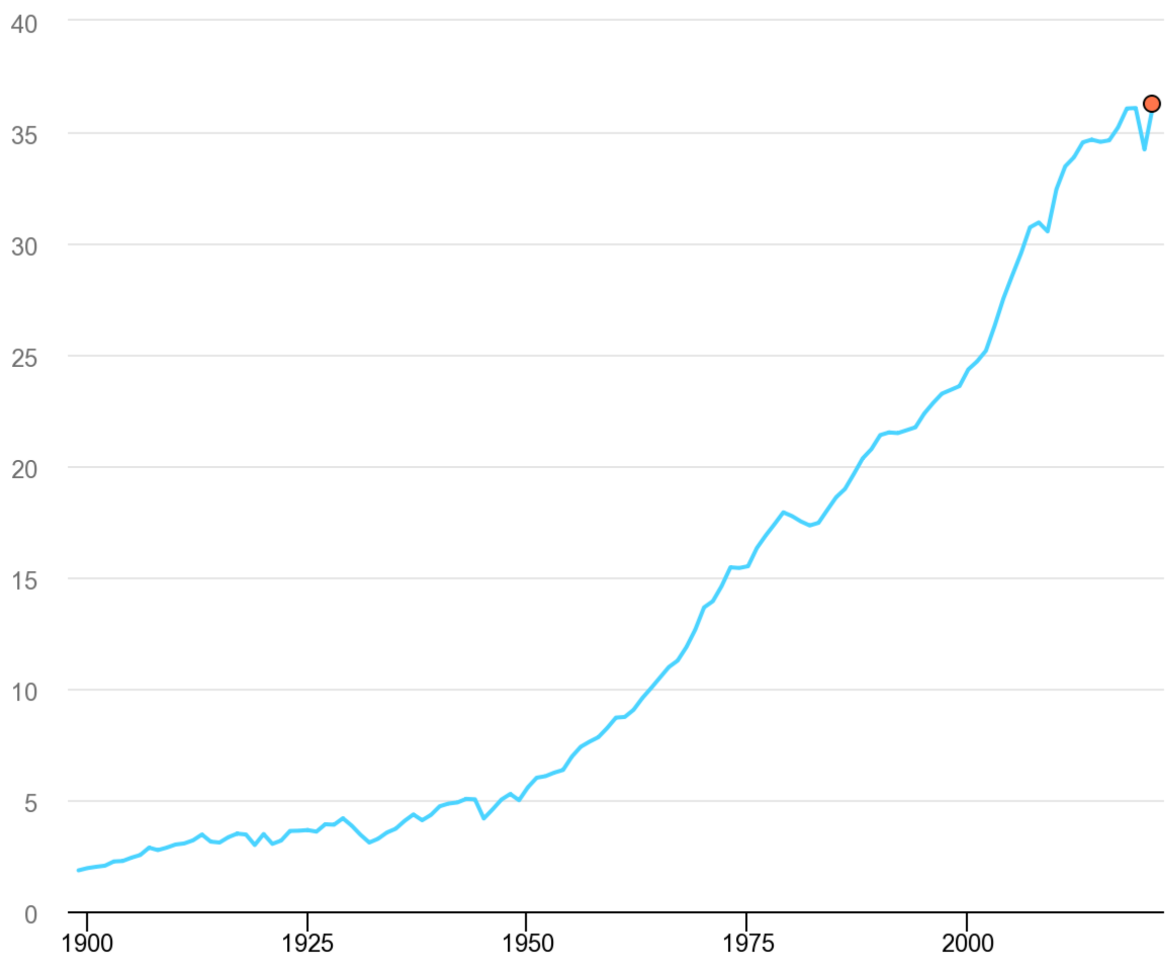

Figure 2. Carbon dioxide emissions from energy combustion and industrial processes, 1900 to 2021. Emissions in 2021 rose to 36.3 gigatonnes, 180 megatonnes above the pre-pandemic level of 2019[9].

The black outline that appears at the center of each map is the boundary for the Stillaguamish and Snohomish Basins. This is much smaller than the usual and accustomed area reserved by the Tulalip Tribes by treaty. However, we include the boundary to help orient treaty resource managers on the map. To that same end, the map below includes elevation for much of the region, as elevation plays an important role in some of the climate change drivers. The connection between climate change drivers and each of the six treaty resource examples, unless otherwise noted, is based on those determined by our UW CIG collaborators as described in the earlier section [see Profiles for Selected Treaty Resources].

[9]International Energy Agency. Global Energy Review: CO2 Emissions in 2021. Accessed at https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2 on July 20, 2022.

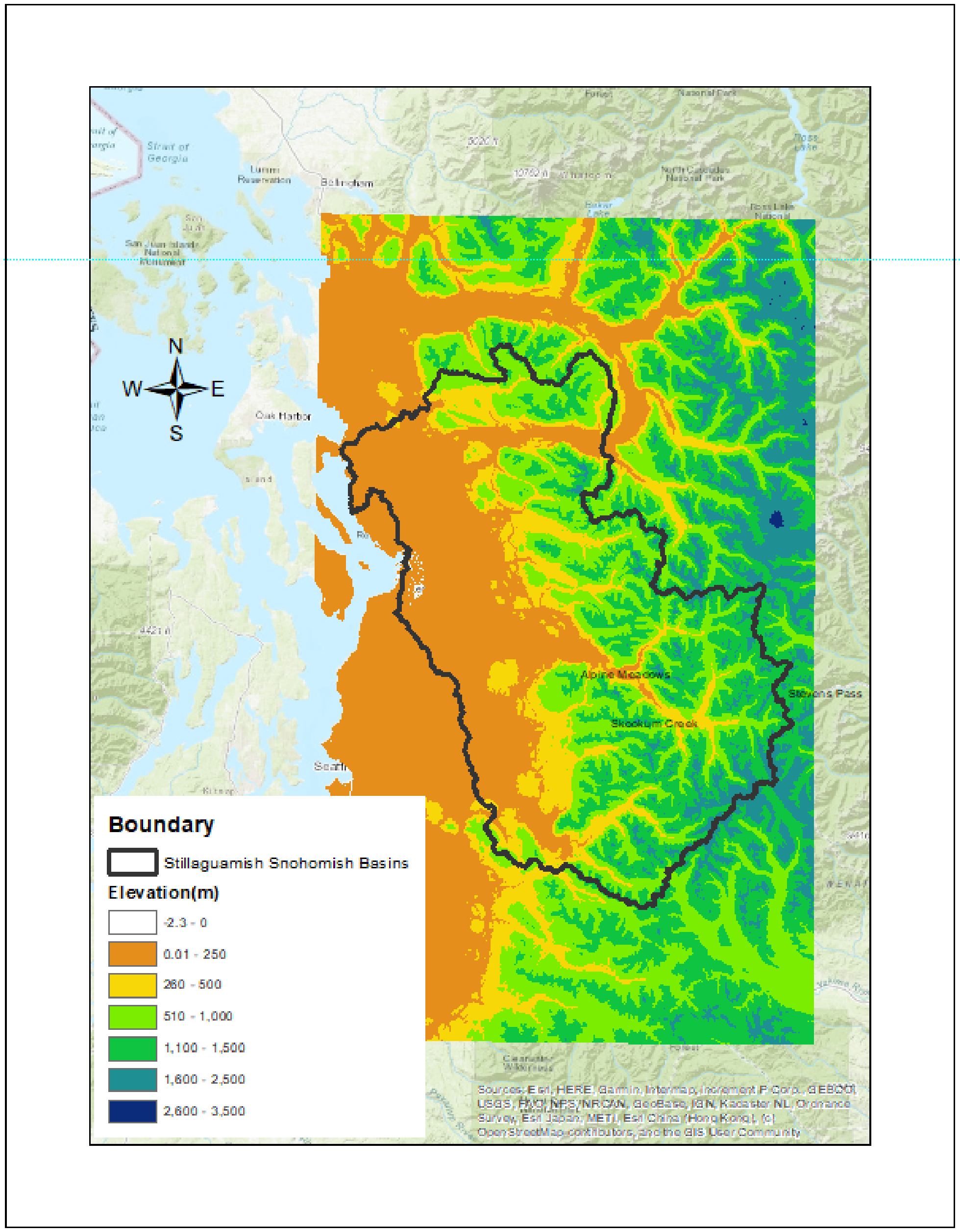

Figure 3. Elevation map of much of the region addressed in this study.

Increases in Air Temperature

Air temperature is a direct climate change driver, leading to increases in both annual and seasonal average air temperatures year by year through the end of the century. Temperatures are predicted to rise in all seasons, day and night. All 20 climate models predict linearly rising annual air temperatures through the end of the century (see Figures 3 and 4 below). The projected average annual change in the region is around 5ºF by mid-century and almost 9ºF by the end of the century. But this is an annual average for the entire year and across the region. Seasonal changes are still somewhat course in resolution and are described below. Changes in temperature in specific places throughout the region also vary from the annual average, but we do not have adequate modeling tools to determine what these changes will be. Nevertheless, variability from place to place throughout our region is important because potential refugia may exist where habitat for important species remains suitable, and where populations may persist.

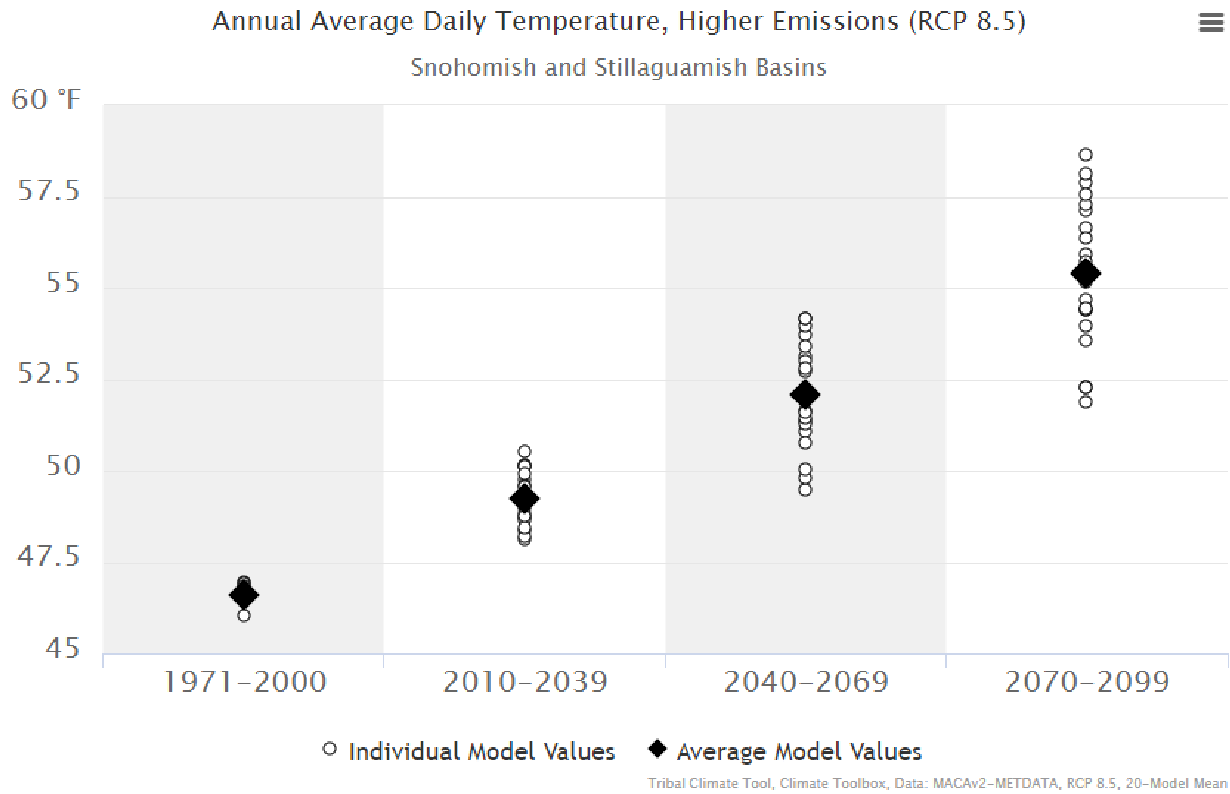

Figure 3. Data points depicting each model result for annual average daily temperatures across the study region.

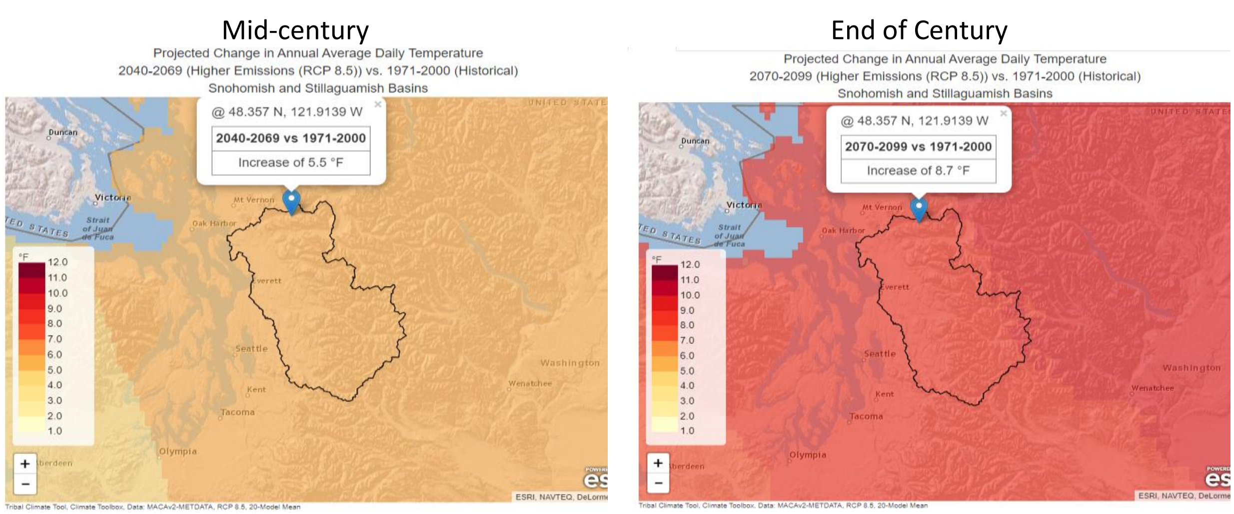

Figure 4. Tribal Climate Tool (UW-CIG) graphic of the change in temperature predicted in mid- and end of this century for our study area.

Increase in summer temperatures

Increases in summer temperatures will be accompanied by decreases in precipitation, so that summers will be hotter and drier. The growing season will expand but soil moisture and stream flow will be reduced more than in the past as the season progresses. Early season plant growth is likely to increase, then as water stress rises due to reduced soil moisture, fire danger may increase (see the UW-CIG State of Knowledge report section on wildfire around Puget Sound). Huckleberry, common camas, Labrador tea, and trailing blackberry will all be affected by these changes. See the species profiles and discussions below for details on these impacts. In the case of Labrador Tea, soil moisture may be maintained in wetlands that are fed by groundwater in contrast to precipitation driven wetlands, which will begin to dry with the conclusion of seasonal precipitation[10]. Western redcedar, and Douglas fir[11,12] are also likely to be affected (see profiles and discussions below). We expect increases in average June – August maximum temperatures of 7ºF by mid-century and almost 11ºF by end of century.

Increase in Spring Temperatures

Though we have no explicit map for it from the Tribal Climate Tool, we expect spring temperatures to increase also[13]. The affect here is the same as warmer temperatures in the rest of the year – less spring precipitation as snow at higher elevations, more rapid runoff, earlier onset of soil drying and low flows in streams. Late season frost where snow has melted early has the potential to damage plants with shallow root systems, such as huckleberry and yellow cedar.

Increase in freeze-free days

With the increase in air temperature will come an increase in the number of days (and nights) without freezing temperatures each year. By mid-century the number of freeze free days is projected to increase, on average, from a 273 days to 325.4 days, and average increase of 52 days. The increase is higher in the highlands. By the end of the century, the tool predicts an average freeze free year with 344 days, an increase of 71 days, leaving on average only 3 weeks of days recording sub-zero days. Gains of more than 100 freeze free days are projected for the highlands. This large reduction in days with sub-freezing temperture should contribute to improved habitat for Western Red Cedar which trees are vulnerable to frost damage in late spring and early fall.

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[10] Dieleman, C.M., Branfireun, B.A., McLaughlin, J.W., Lindo, Z. 2015. Climate change drives a shift in peatland ecosystem plant community: Implications for ecosystem function and stability. *Global Change Biology* 21, 388-395. doi: 10.1111/gcb.12643

[11] Littell, J.S.; Oneil, E.E.; McKenzie, D. [et al.]. 2010. Forest ecosystems, disturbance, and climatic change in Washington state, USA. *Climatic Change*. 102: 129–158.

[12] Rehfeldt, et al. 2014. Comparative genetic responses to climate for the varieties of *Pinus ponderosa* and *Pseudotsuga Menseisii*: Realized climate niches. Forest Ecology and Management, 324: 126-137. http://dx.doi.org/10.1016/j.foreco.2014.02.035

[13] Climate Change in the Northwest: Implications for Our Landscapes, Waters, and Communities. Choice Reviews Online 2014, 51 (11), 51-6191-51–6191. https://doi.org/10.5860/CHOICE.51-6191.

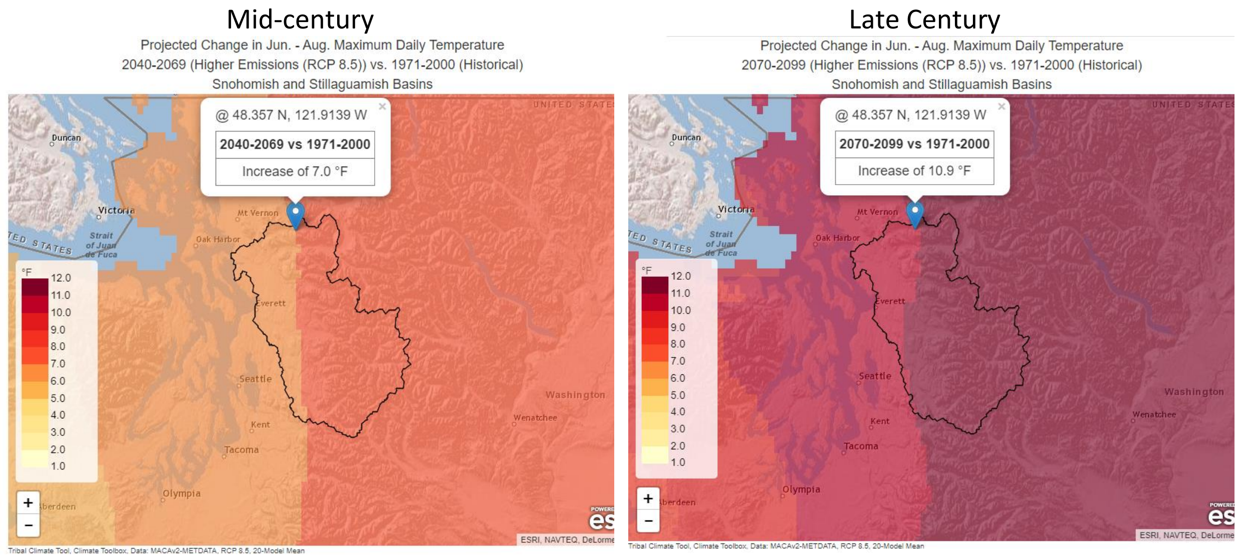


Figure 5. Tribal Climate Took (UW-CIG) graphic of projected change in June through August maximum daily temperature for mid- and late of century for our study area.

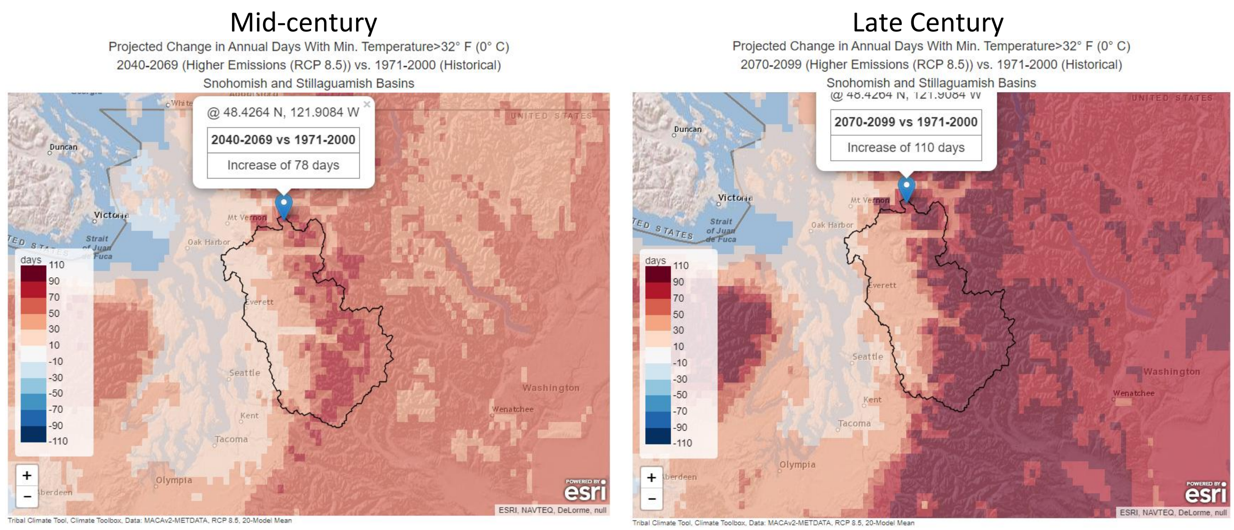


Figure 6. Tribal Climate Tool (UW-CIG) graphic of projected change in annual number of days with temperatures greater than freezing for mid- and late of century in our study area.

Increase in the Mean Winter Freezing Elevation (Snow Line)

The mean winter freezing level (snow line) in the North Cascades has risen about 650 feet in elevation[14]. Plants the require snow cover to survive winter temperatures will need to migrate up-slope with the snow line. As temperatures continue to rise, so will the snow line and its associated ecological conditions.

[14]North Cascades National Park: Climate Change Resource Brief. Accessed at https://www.nps.gov/noca/learn/nature/climate-change-resource-brief.htm on July 21, 2022.

Increase in the Length of the Growing Season

Finally, another change driven by increases air temperature is the increase in the length of the growing season, defined by the average number of consecutive days each year when the minimum daily temperature remains above freezing at 32°F (0°C).

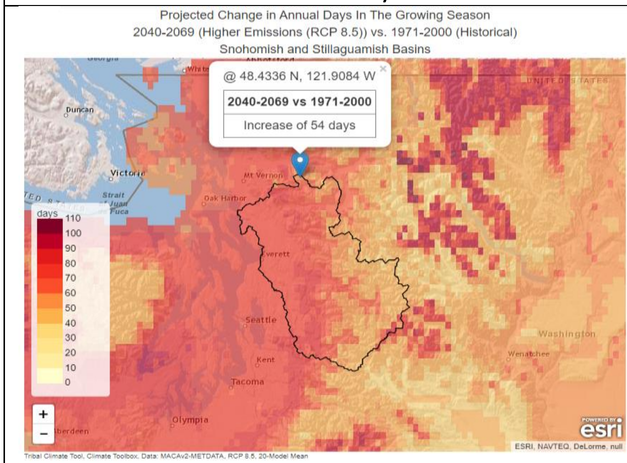
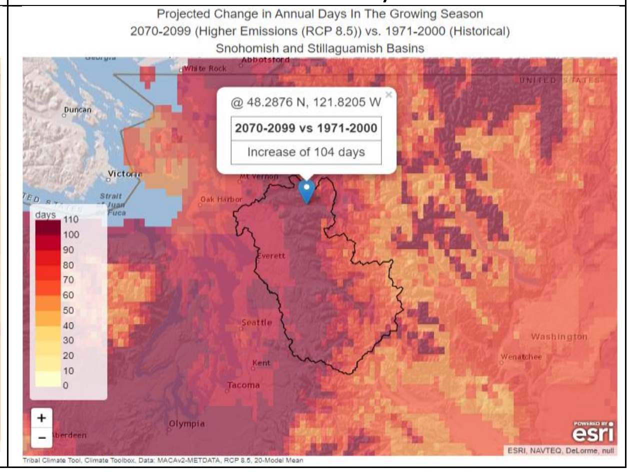
Mid-century	Late Century
	

Figure 7. Tribal Climate Tool (UW-CIG) graphic of projected change in the length of the growing season for mid- and late of century for our study area.

In the mid-century, the annual number of days in the growing season is projected to be 256 days, an increase of 65 days from the historical value of 190 days – a projected increase of 34%. Increases are higher in the lowlands (~ 80 days) than the highlands (~45 days). In the late century, the projected length of the growing season is projected to be 285 days, an increase of over 95 days (50%) compared to historic values, and would represent almost 10 months of consecutive days above freezing.

The lengthened growing season could lead to wider spread of reed canary grass, and other invasive species that can adversely affect plants important to Tulalip Tribes.

It should be noted that while the growing season is lengthening, the potential positive effect may be overwhelmed by increases in spring and summer Air Temperature (see above) and decreases in Soil Moisture (see below) will adversely affect the growth of treaty resources that require adequate soil moisture to prosper.

The lengthening of the growing seasons will have many impacts as it impacts current species phenology. As mentioned in the earlier section [see Environmental Effects of Climate Change] a lack of sufficiently cold air temperatures may delay leaf emergence. Studies of Douglas fir in western Washington and Oregon have found that warmer air temperatures may result in earlier spring growth initiation, but that rising winter air temperatures could lead to delayed leaf emergence due to an unfulfilled winter chill requirement.

In this section, trends in landscape conditions are organized into those that are related to the direct climate change drivers – Air Temperature and Precipitation – and Soil Moisture, which is driven by both, and also affected by topography, soils, landcover and hydrology. Finally, there is a brief discussion of those conditions for which Tribal Climate Tools maps are not available.

Changes in Precipitation Patterns

The second core driver associated with climate change is changes in precipitation patterns – timing, intensity and quantity. Projections for changes in annual amounts of precipitation (rain and snow) from the 20 climate models are more varied than temperature predictions, with the majority projecting a slight increase in precipitation, but a few seeing little or none.

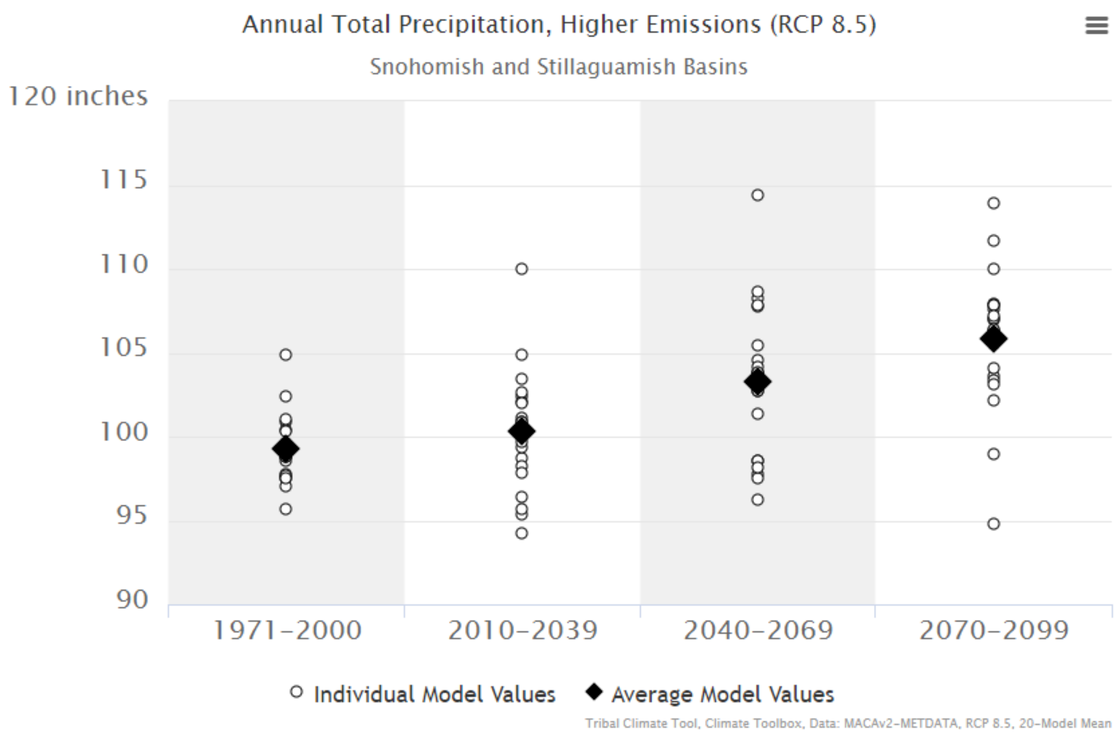


Figure 8. Data points depicting each model result for annual total precipitation across the study region.

Annual Precipitation

As the quantity and mode of precipitation is greatly influenced by elevation, so too is the spatial distribution of projected changes in annual precipitation. In 2070-2099 (higher emissions), the annual total precipitation is projected to be 105.8 inches, an increase of 6.5 inches from the historical value, and 14 inches in higher areas of elevation.

Increase in Winter Precipitation

In the mid-century, the Oct. - Mar. total precipitation is projected to be 76.4 inches, an increase of 4.7 inches from the historical value. In the late century, that will increase in 80.1 inches, an increase of 8.5 inches. Again, the largest increases will be in the highlands.

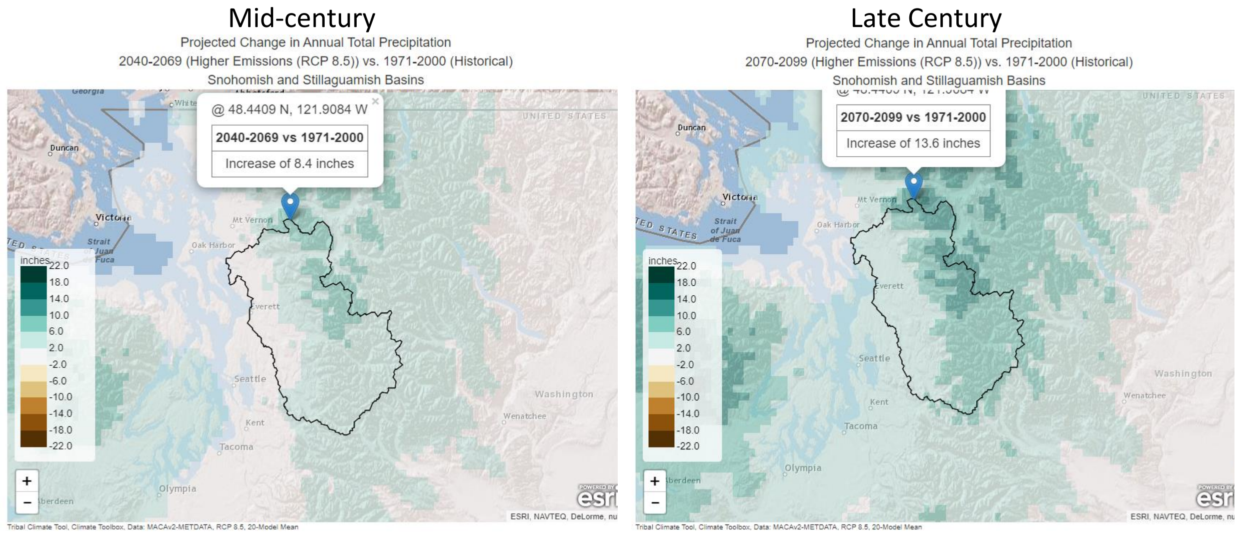


Figure 9. Tribal Climate Tool (UW-CIG) graphic of projected change in annual total precipitation across our study area in mid- and late of century.

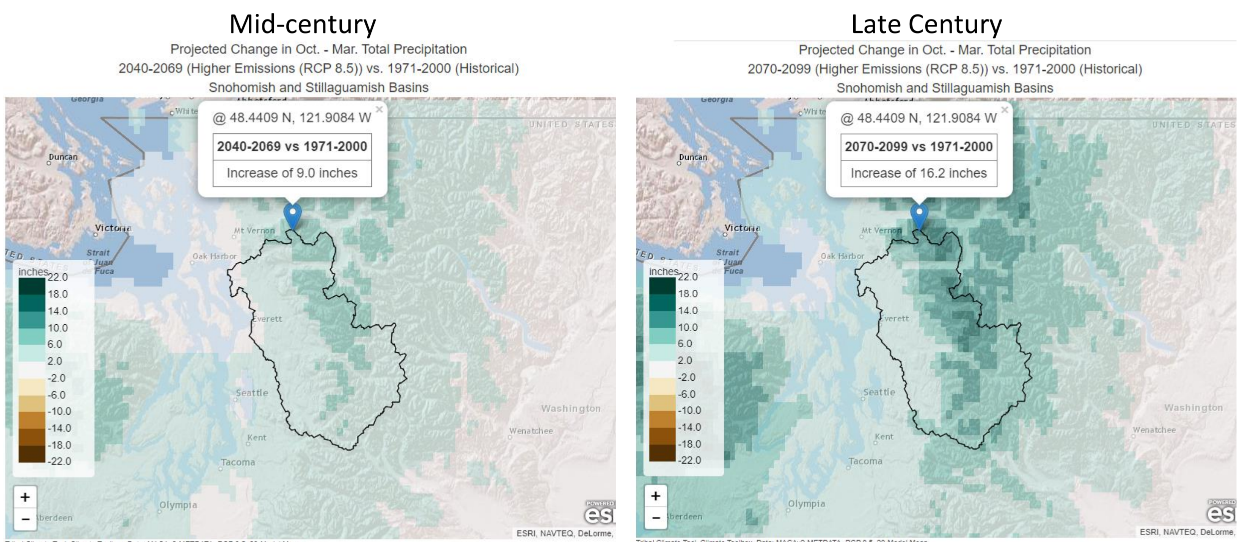


Figure 10. Tribal Climate Tool (UW-CIG) graphic of projected change in the total precipitation Oct through March across our study area for mid- and late of century.

The likely increase in early spring precipitation should increase soil moisture which may enhance growth in the meadows where Common Camas occurs. On the other hand, increased soil moisture in the winter months makes larger trees in the Western Hemlock Zone, especially Western Red Cedar, more susceptible to windthrow.

Decrease in Summer Precipitation

The picture in spring and summer months (April – September) is, on average, expected to be somewhat drier across the region. In Mid-century, average total precipitation in summer and fall months is projected to be 26.8 inches, a decrease of 0.8 inches from the historical value, with a further decrease in the late century to 25.6 inches, a decrease of 2.0 inches from the historical value of 27.6 inches in the two basins. This summer water deficit, combined with decreasing summer moisture levels (see below), will decrease habitat suitable for Common Camas, and reduce berry production for the Trailing Blackberry.

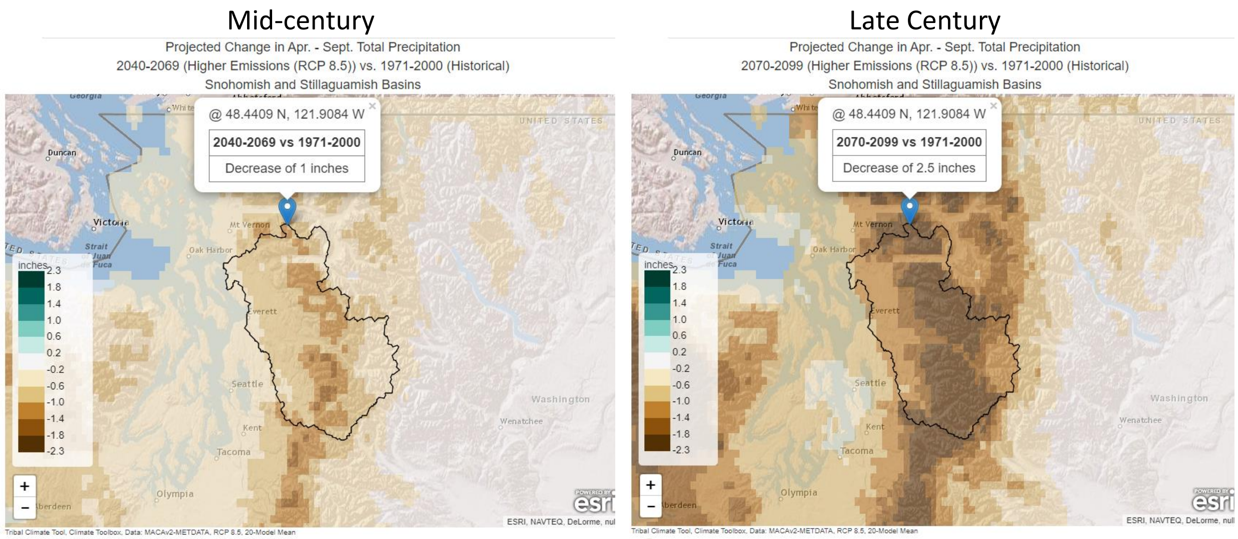


Figure 11. Tribal Climate Tool (UW-CIG) graphic of projected change in the total precipitation April through September across our study area for mid- and late of century.

Decrease in Spring Snowpack

Critical to the basins whose main rivers are augmented in spring and summer by snow melt, is the amount of water stored in the Cascades snowpack each year. The amount is typically represented as Snow Water Equivalent (SWE) – the equivalence between a column of snow and depth of liquid water if the snow was melted. Historically, SWE peaks in the Cascades in April-May, so SWE as measured on April 1st is a measure that speaks to water reserves in snowpack for the spring and summer runoff.

Mid-century Late Century

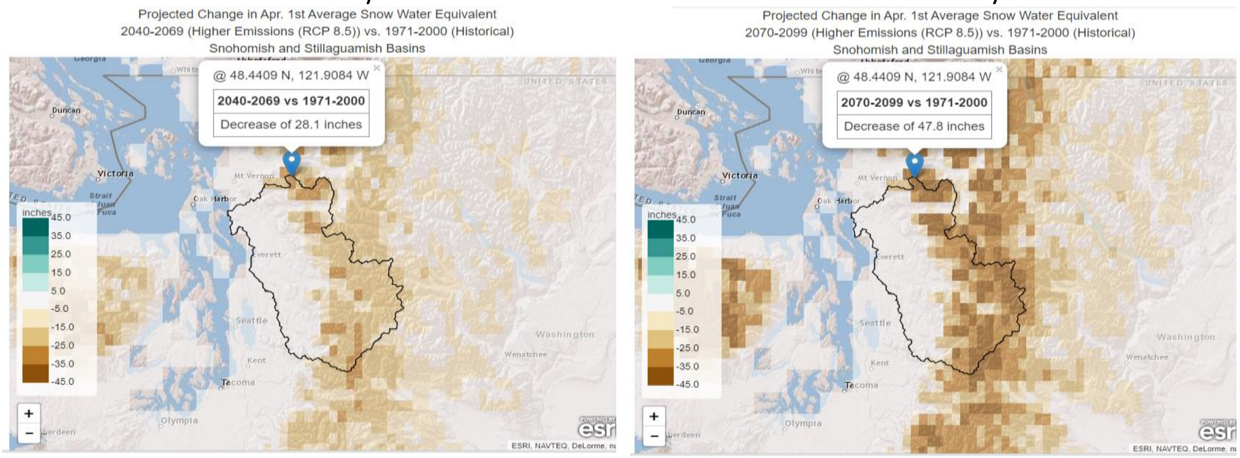


Figure 12. Tribal Climate Tool (UW-CIG) graphic of projected change in the Snow Water Equivalent on April 1 at Snotel stations across our study area for mid- and late of century.

In mid-century, the April 1st average SWE is projected to be 10.6 inches, a decrease of 11.1 inches from the historical value of 21.7 inches – a decrease in volume of 51%. In late century, the Apr. 1st average snow water equivalent is projected to be 4.6 inches, a decrease of 17.1 inches or 80% from the historical value. These changes occur above the mean winter freezing level (snow line). The mean winter freezing level in the North Cascades has risen about 650 feet since 1950[15]. We are not aware of modeling results that predicts the rise of the snow line over time, but it is reasonable to assume it will be much higher by mid and late in this century.

The loss of snowpack may well combine with decreasing soil moisture in late spring (see below) to impact growth of both Common Camas and Labrador Tea.

For perennial plants such as Big Huckleberry that are susceptible to frost, snow acts as an insulator during the winter. While the depth of snow on the ground is not the same as SWE, the two are generally related, with Snow Depth about twice. So, the changes in SWE suggest that Big Huckleberry may be more at risk from spring frosts. We are working on a project to directly estimate changes in the spatial distribution of snow in the early spring.

Changes in Soil Moisture

Decreasing Summer Soil Moisture

Changes in Air Temperature and Precipitation patterns combined with soil data and hydrology lead to changes in soil moisture, a critical element in the habitat of many species. Soil Moisture can be expressed as the amount of water contained in the upper meters of soil.

[15]National Park Service: Climate Change Resource Brief. Accessed at https://www.nps.gov/noca/learn/nature/climate-change-resource-brief.htm on July 20, 2022.

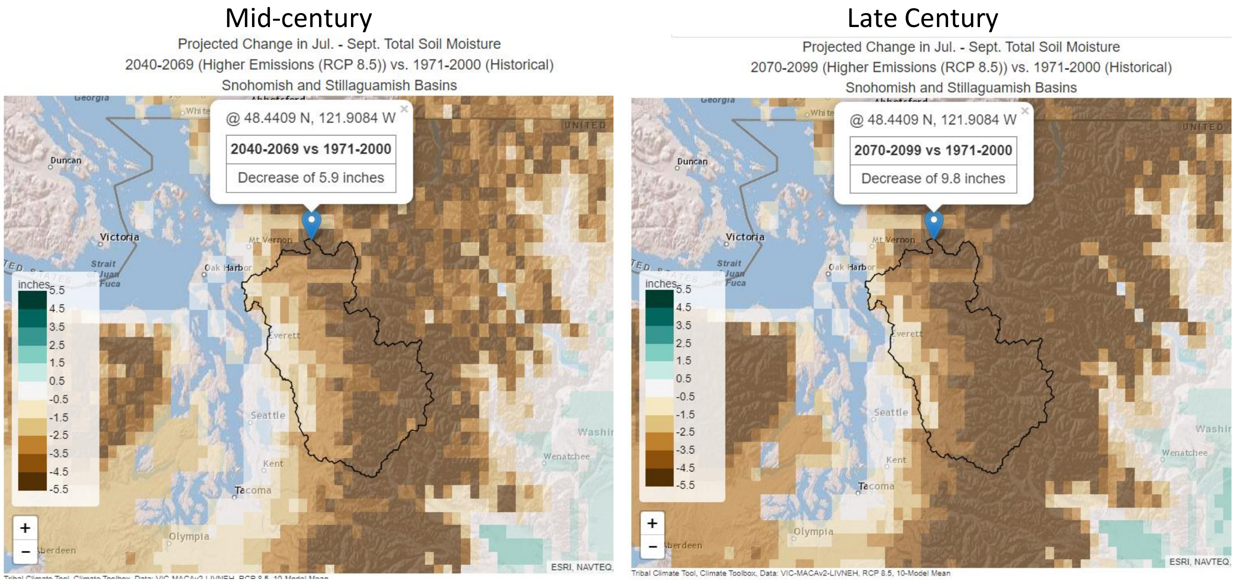


Figure 13. Tribal Climate Tool (UW-CIG) graphic of projected change in total soil moisture from July to September across our study area for mid- and late of century.

In mid-century, summer total soil moisture is projected to be 22.7 inches, a decrease of 4.1 inches from the historical value of 26.8. In the late century, summer total soil moisture is projected to be 21.0 inches, a decrease of 5.8 inches – almost 22%. The largest changes occur at mid to higher elevations.

Decreases in summer soil moisture may cause dieback in Western Red Cedar and limit growth of Douglas Fir, and will impact the growth of Common Camas and Trailing Blackberry. As well as impacting the growth of Labrador Tea, decreasing soil moisture will also lower the water table, reducing suitable wetland habitat for this species.

Decreases in Spring soil moisture will impact growth of Big Huckleberry, and we need estimates of the changes in soils moisture – distribution and quantity - in the spring months to understand the extent.

As mentioned before, an increase of precipitation and snow melt in late-winter and early spring may produce an increase in soil moisture which may result in increased wind throw of Western Red Cedar. We are working on more refined estimates of soil moisture – in terms of distribution, timing and quantity.

Climate Change effects without map projections

The Tribal Climate Tool has been an invaluable source of information of projected drivers of climate change that will change the habitat of our treaty resources. However, we need finer resolution – both spatially and temporarily – and some different measures of summer water surface deficit, wetlands area, Winter Snow Depth, spring precipitation and temperatures to better represent the changed landscape of the future. We are working on a project using EPA's

VELMA eco-hydrology system to connect projected air temperature and precipitation to biomass growth and hydrology through the end of the century. This project should provide these finer projections and allow us to update this work.

Summary of Climate Change Drivers' impacts on 6 Treaty Resources

The following table summarizes the links between expected changes in landscape conditions due to climate change the effect of those changes on the selected Treaty Resources

Treaty Resource	Landscape Condition/Trends	Indicator	How Treaty Resource is affected
Labrador Tea	Air Temperature - Increasing	Mean Air Temperature in Spring and Summer	If sufficient moisture available, increases growth
	Spring Snowpack- Decreasing	Snow SWE on April 1st	Decreasing snowpack in early spring reduces soil moisture needed for growth
	Soil Moisture/Summer Drought - Decreasing/Increasing	Average Soil Moisture in Summer	Low Soil moisture reduces wet soils needed for growth
	Wetlands water levels Decreasing	Minimum Soil Moisture in Summer	Decreases habitat by reducing wetland water levels
Western hemlock zone	Summer Soil Moisture - Decreasing	Mean Soil Moisture in Summer	Low Soil moisture limits Douglas Fir growth, causes WRC dieback
	Summer Air Temperature - Increasing	Mean Air Temperature in Summer	High temperature limits Douglas Fir growth, causes WRC dieback
	Frost Free Season - Lengthening	Days with air temperature greater than freezing	Reduces WRC exposure to spring frosts
Big huckleberry	Summer Air Temperature - Increasing	Mean Air Temperature in Summer	reduces Soil moisture needed for growth
	Spring Air Temperature - Increasing	Mean Air Temperature in Spring	reduces Soil moisture needed for growth
	Deep Snow - Decreasing	Minimum Snow Depth on freezing days	protects plants from freezing temperatures
	Growing Degree Days - Increasing	Number of contiguous days above freezing in spring	huckleberry flowers earlier in spring
	Late Season Frost Exposure - increasing	Number of freezing days in flowering period	late spring frosts damage early flowering plants, reducing fruit production
Western red cedar	Summer Soil Moisture - Decreasing	Mean Soil Moisture in Summer	Low soil moisture causes dieback

	Summer Air Temperature - Increasing	Mean Air Temperature in Summer	High temperature limits causes dieback
	Winter Precipitation - Increasing	Mean precipitation in Winter	increased saturated soils leads to increased windthrow
	Frost Free Season - Lengthening	Number of above-freezing days each year	reduces number of days when frost inflicts damage
Trailing Blackberry	Soil Moisture/Summer Drought - Decreasing/Increasing	Mean Soil Moisture in Summer	soil moisture needed for berry production
Trailing Blackberry	Summer Precipitation - Decreasing	Mean precipitation in Summer	soil moisture needed for berry production
Common Camas	Growing Season - Lengthening	Number of contiguous days above freezing in spring	increased growth of invasive reed canary grass
	Spring Precipitation - Increasing	Mean Precipitation in Spring	increased soil moisture for growth in Spring
	Spring Snowpack - Decreasing	Mean Snow Water Equivalent in Spring	reduced soil moisture for growth in Spring
	Spring Air Temperature-Increasing	Mean Air Temperature in Spring	reduced soil moisture for growth in Spring
	Summer Soil Moisture - Decreasing	Mean Soil Moisture in Summer	reduced soil moisture in Summer
	Summer water deficit - Increasing	Mean Surface water in Summer	reduced soil moisture in Summer