WASHINGTON NATURAL HERITAGE PROGRAM

Assessing the Climate Change Vulnerability of Washington's Wetlands

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Prepared by

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Assessing the Climate Change Vulnerability of Washington's Wetlands

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ON THE COVER: North Pacific Open Bog & Acidic Fen (G284) at Dailey Prairie Natural Area Preserve. This US National Vegetation Classification group received a climate change vulnerability rank of 'high' (Photo by Tynan Ramm-Granberg)

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Acknowledgements

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Anthony Stewart and colleagues at the University of Washington contributed a great deal to the exposure section of this protocol, including much of the data extraction and metric development. We thank them for their contributions!

1 Introduction

Wetland biota and ecological processes are closely tied to regional and local climate patterns. Change to temperature regimes and precipitation patterns have the potential to result in significant changes to Washington's wetlands. Wetland ecosystem response to climate change will be complex and entail changes to a variety of ecological processes and numerous species. The degree and severity of these changes will vary across Washington's ecoregions and specific wetland types, where elevation, climate, geology, soils, water source, hydrological regime, and biota differ (Ashton, 2010; Halofsky et al., 2011; Mauger et al., 2015).

It is challenging to integrate the variety of potential climate change responses of wetland ecosystems into meaningful guidance for land managers, conservation practitioners, and regulators. A set of standardized indicators, relativized to ecologically specific wetland types, can provide systematic, cost-effective, and ecologically meaningful information about wetland vulnerability to climate change. Such indicators not only provide a measure of which wetland types are sensitive but can also guide long-term monitoring designs to detect climate change effects. Coupled with measures of wetland condition (such as WNHP's Ecological Integrity Assessment (EIA); https://www.dnr.wa.gov/NHP-EIA), climate change vulnerability assessments could help identify feedback loops between wetland condition and climate resilience. For example, Nahlik and Fennessey (2016) found that carbon stored in wetlands diminished with increasing human disturbance, suggesting wetlands impacted by human stressors are sources of carbon and thus contribute to climate change. Globally, peatlands (bogs and fens) store more carbon than any other terrestrial ecosystems (Parish et al., 2008). As such, peatland types found to be highly vulnerable to climate change should be an important target for conservation and management actions that maintain or restore climate resilience and prevent additional release of carbon to the atmosphere. Additional feedback loops identified via vulnerability assessments may help guide management actions to efficiently improve climate resiliency.

Understanding vulnerability of regional wetland types to climate change impacts is critical for regulatory mechanisms (providing feasible mitigation guidance, setting appropriate performance standards, assessing long-term viability of mitigation banks, etc.). Such information is also critical for making effective conservation acquisitions. Acquiring conservation lands may be risky if the conservation target is highly vulnerable to impending climate change impacts.

Climate change vulnerability can be assessed at different ecological scales, ranging from individual species (Young et al., 2016; Fertig, 2020, 2022) to landscape assessments (Walker & Pellatt, 2008; Ashton, 2010; Halofsky et al., 2011). Few methods have been developed for assessing ecological scales between these extremes, targeting mid-scale ecosystem types. NatureServe assessed climate change vulnerability of upland ecological systems across the western United States, but did not assess wetlands (Comer et al., 2019). With support from the Washington Natural Heritage Program (WNHP), the Washington Department of Fish and Wildlife assessed numerous ecological systems of concern, but did not review all wetland types. These assessments were also completed at an ecological resolution that is insufficient for addressing a broader range of information needs (WDFW, 2015). Halabisky et al. (2017) and Halabisky (2017) conducted a spatially explicit, regional assessment of wetland climate change vulnerability in the northern Columbia basin, but that assessment was solely focused on hydrological responses and did not consider biotic components. This project seeks to address these data gaps via an assessment framework for estimating the climate change vulnerability of mid-scale wetland ecosystem types to inform management, conservation, and regulatory decisions for increased climate resilience.

2 Methods

2.1 Overview

We took the following steps to develop and deploy a Wetland Ecosystem Climate Change Vulnerability Assessment (WetEco CCVA): 1.) Identified the wetland assessment system and units to be used 2.) Worked with Dr. Anthony Stewart and colleagues at the University of Washington (UW) to select appropriate climate model and summarize data for exposure metrics, 3.) Reviewed and evaluated existing CCVA protocols for both ecosystems and species, 4.) Developed a new protocol based on our review of existing protocols, 5.) Compiled exposure metrics for all wetland ecosystems, 6.) Tested and revised protocol on U.S. National Vegetation Classification (USNVC) group North Pacific Open Bog & Acidic Fen (G284), and 7.) Reviewed and shared results.

The WetEco CCVA is a metric-based protocol for systematically assessing the vulnerability of mid-scale wetland ecosystem types. The protocol is tailored to the biotic and abiotic components of Washington's wetland types. It is divided into three categories (Exposure, Adaptive Capacity, and Threats) that are then integrated to produce an overall Climate Change Vulnerability score and rank.

2.2 Wetland Assessment Units

Wetland ecosystem assessment units are defined using the USNVC (Faber-Langendoen et al., 2014, 2018, 2025). The USNVC classifies vegetation according to shared physiognomy, floristics, biogeography, and ecological relationships. These properties make the USNVC an ideal system for constraining ecological variability within our assessment units.

The USNVC has a hierarchical structure that provides a common language for the effective management and conservation of plant communities across the United States. It is supported by the Federal Geographic Data Committee (FGDC, 2008), NatureServe (Faber-Langendoen et al., 2009), and the Ecological Society of America (Jennings et al., 2009). The classification standard was developed over many years by the FGDC Vegetation Subcommittee (FGDC, 2008), with members from diverse federal agencies, the Vegetation Panel of the Ecological Society of America, and NatureServe (https://usnvc.org/about/). The USNVC is intended to allow federal agencies to produce uniform statistics about vegetation resources across the nation, facilitate interagency cooperation on vegetation management issues that transcend jurisdictional boundaries, and encourage non-Federal partners to utilize and contribute to a common system when working with their federal partners.

The USNVC consists of eight levels. The three upper levels are based primarily on physiognomic-structural characteristics within a global ecological context; the three middle levels incorporate diagnostic species and life forms sorted by biogeographic and regional ecological drivers; and the two lower levels—alliance and association—reflect floristic similarities based on regional, sub-regional and topoedaphic climate, substrates, hydrology, and disturbance regimes (Figure 1) (FGDC, 2008; Faber-Langendoen et al., 2014).

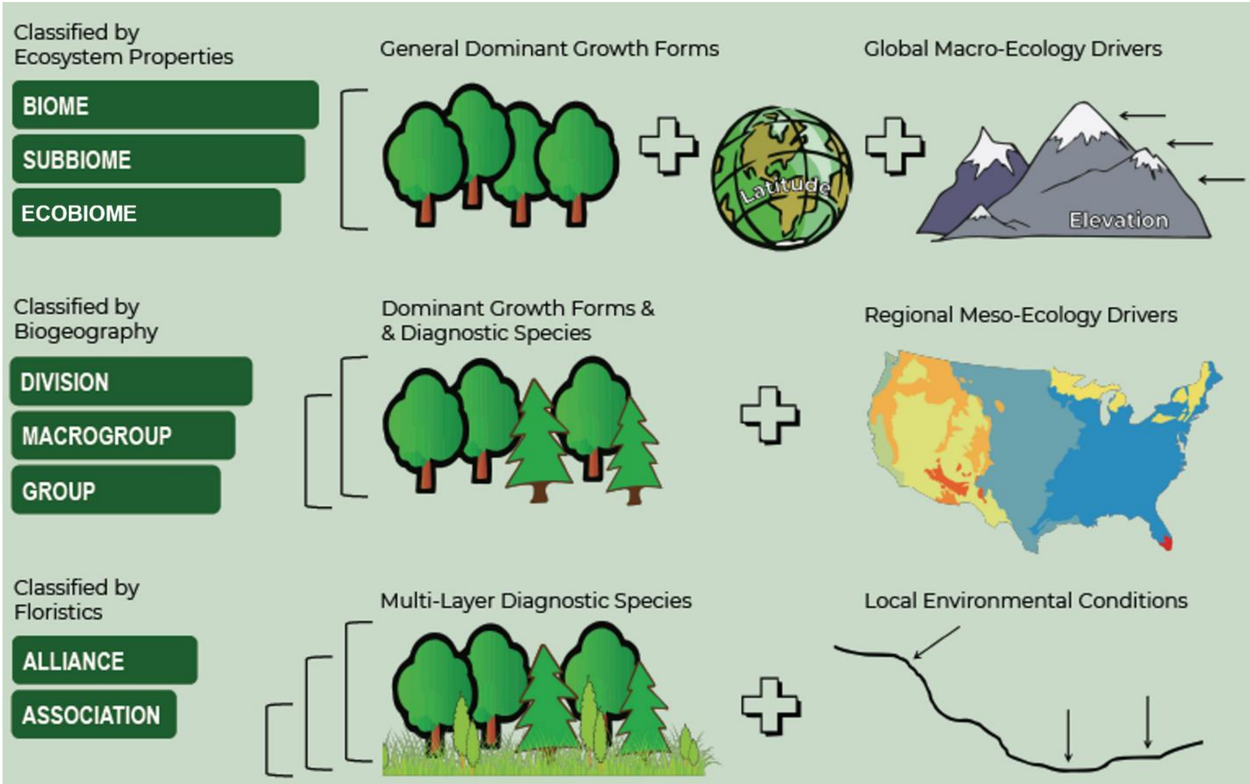

Figure 1. The U.S. National Vegetation Classification Hierarchy.

USNVC classification units—regardless of hierarchy level—are derived from scientific literature, quantitative data sets, and professional expertise and undergo a rigorous peer-review process.

2.2.1 USNVC Groups & Alliances

The WetEco CCVA protocol focuses on USNVC groups as the primary assessment units. Groups reflect wetland vegetation and ecological variation at a regional scale. They incorporate primary ecological drivers such as hydrological regime, soil types, and biogeographical patterns in vegetation composition and structure (Faber-Langendoen et al., 2014, 2018). These attributes allow us to constrain natural variability so that climate change signals are more readily apparent. Within each group, the WetEco CCVA also evaluates component alliances to determine if finer scale units within the group may have different ecological responses to climate change than the group as a whole.

2.3 Protocol Development

2.3.1 Structure

The goal was to create a protocol with the following attributes:

1) Applicable to mid-scale wetland ecosystems types.

2) Integrates both biotic and abiotic responses to climate.

3) Assesses the vulnerability of ecosystem types rather than specific locations.

We reviewed several other climate change vulnerability assessment methods in the process of developing the WetEco CCVA. In particular, we drew heavily on methods developed by NatureServe, including the Climate Change Vulnerability Index (CCVI) (Young et al., 2016; Lyons et al., 2024) and the Habitat Climate Change Vulnerability Index (HCCVI) (Comer et al., 2019). As part of NatureServe's network of natural heritage programs, our goal was to create methods compatible with NatureServe's pre-existing CCVA protocols.

Though we prioritized pre-existing NatureServe methods in the development of this protocol, we also reviewed several other CCVA methods that helped refine our protocol. A CCVA of California's terrestrial vegetation was helpful in deciding how to assess the vulnerability of key component species (Thorne et al., 2016). Several previous CCVAs and similar evaluations done for other ecosystems or species in the Pacific Northwest were used to help refine metrics and set evaluation criteria for metrics (Lawler & Mathias, 2007; Walker & Pellatt, 2008; Coops & Waring, 2011; Abatzoglou et al., 2014; Halabisky et al., 2017; Kerns et al., 2018; Halofsky et al., 2020, 2022; Salathé et al., 2023). We also reviewed several wetland focused CCVAs and similar evaluations done outside the Pacific Northwest while selecting and refining our metrics (Day et al., 2008; Swanston et al., 2011; Perry et al., 2012; Kominoski et al., 2013; Lee et al., 2015; Renou-Wilson & Wilson, 2018; Defne et al., 2020; Closs et al., 2024).

While details vary, most existing methods divide climate change vulnerability metrics into three standard categories: (1) Sensitivity, (2) Adaptive Capacity, and (3) Exposure (Schneider et al., 2007; Williams et al., 2008). We found the distinction between sensitivity and adaptive capacity to be hazy (as have others, see Smith et al., 2017; Thurman et al., 2020) and chose to fold discussions of sensitivity into the adaptive capacity section. We then added a separate threats section, as in CCVI 4.0 (Lyons et al., 2024). Though Comer et al. (2019) retained sensitivity as a section name, they also focused this category on the effects of anthropogenic stressors on evaluated ecosystems, and this also informed our decision to exchange sensitivity for threats.

The structure and content of the adaptive capacity section is modeled after an attribute-based framework proposed by Thurman et al. (2020) that is also used by CCVI 4.0 (Lyons et al., 2024). That framework was designed for assessing species, so we used a subset of its modules that are most relevant to ecosystem adaptive capacity (see Adaptive Capacity below for further discussion of adjustments to the framework).

2.3.2 Metrics

The WetEco CCVA method is designed for assessment of wetland ecosystems, so we wanted to thoroughly capture exposure, adaptive capacity, and threats related to hydrology. With significant input from Dr. Anthony Stewart and colleagues at the University of Washington (UW), we expanded and subdivided selected exposure metrics to include several climate variables that can affect hydrology and water balance, including total annual precipitation, magnitude of extreme precipitation events, changes in snowpack, summer maximum temperature, and precipitation drought. Our Adaptive Capacity section correspondingly expanded to assess responses to these exposure variables. We also selected metrics for assessing the importance of other abiotic variables (particularly hydrological conditions), ecosystem range and distribution, and the vulnerability of the biotic community.

After compiling metrics from existing methods, we looked for significant gaps in climate exposure, biotic or abiotic responses to climate change, or ancillary threats that could interact with climate change. As part of this exercise, we reviewed wetland ecosystem classification resources (e.g., Rocchio & Crawford, 2015; Rocchio & Ramm-Granberg, 2022; USNVC, 2022) to make sure that relevant ecological processes were being considered. We then determined whether we had sufficient data and/or professional expertise to capture these in the WetEco CCVA.

During testing, we also merged metrics we found to be duplicative. For example, draft exposure metrics developed with UW initially included a metric for likelihood of fire conditions. However, this metric is based on climate conditions such as summer drought, summer temperatures, and the previous year's snowpack. We chose to drop likelihood of wildfire conditions from our metrics because the climate variables that informed this metric were assessed elsewhere in our protocol. Fire is less likely to be a direct disturbance in wetland ecosystems, so effects of fire can be discussed as a potential consequence to changes in these individual metrics. The upland ecosystems that merit consideration of likelihood of fire conditions as an independent exposure and adaptive capacity metric are outside the scope of this protocol.

2.3.3 Trial Application

After developing the protocol structure and testing individual metrics, we assessed the exposure metrics for all wetland groups in Washington. A full WetEco CCVA was also completed for a single USNVC group, North Pacific Open Bog & Acidic Fen (G284). We selected this group to test the WetEco CCVA methods for two reasons. First, there is considerable interest in peatlands as important carbon sinks (Parish et al., 2008) and some consider these ecosystems to be particularly vulnerable to climate change (Bridgham et al., 2008; Ise et al., 2008; Renou-Wilson & Wilson, 2018). Second, WNHP staff have significant professional expertise with this group, providing important context as we tested method.

The results of our WetEco CCVA for the North Pacific Open Bog & Acidic Fen Group are summarized in the Results section and presented in full in Appendix A.

2.4 Wetland Ecosystem Climate Change Vulnerability Assessment

The WetEco CCVA consists of 18 metrics subdivided into three categories: Exposure, Adaptive Capacity, and Threats (Table 1). Exposure is the modeled change in climate variables where the ecosystem type occurs. Adaptive Capacity evaluates an ecosystem's ability to respond and adapt to climate exposure. The Threats section evaluates how other anthropogenic stressors may interact with the effects of climate change. Together, these categories are integrated to produce an overall Climate Vulnerability score and rank.

Table 1. Wetland Ecosystem Climate Change Vulnerability Assessment metrics, subdivided by category.

Category	Metric
Exposure 45% of final score	EX1. Total Annual Precipitation
	EX2. Extreme Precipitation Magnitude
	EX3. Snowpack *Submetrics* EX3.1 Snow Drought by April 1st EX3.2 Snowpack Change

	EX4. Summer Maximum Temperature
	EX5. Precipitation Drought in Summer
	EX6. Sea Level Rise
Adaptive Capacity 45% of final score	AC1. Adaptive Capacity to Total Annual Precipitation
	AC2. Adaptive Capacity to Extreme Precipitation Magnitude
	AC3. Adaptive Capacity to Snowpack Change
	AC4. Adaptive Capacity to Summer Maximum Temperature
	AC5. Adaptive Capacity to Precipitation Drought in Summer
	AC6. Sea Level Rise
	AC7. Diversity of Biophysical Settings and Variability of Supporting Hydrological Conditions
	AC8. Current Extent
	AC9. Location within Geographic Range
	AC10. Vulnerability and Redundancy of Key Component Species *Submetrics* AC10.1 Vulnerability of Key Species AC10.2 Redundancy of Key Species
Threats 10% of final score	TH1. Current Ecological Integrity of Extant Occurrences
	TH2. Potential for Climate Change to Exacerbate Existing Stressors

2.4.1 General Guidelines

All ratings should be accompanied by a discussion of the supporting evidence.

In many cases, available information will be contradictory or involve a high degree of uncertainty. The assessor will need to evaluate which conclusions or predictions are supported by more evidence, with greater weight given to data from Washington State and/or the greater Pacific Northwest, when available. The assessor should explain why they choose to prioritize certain data points above others. If contradictory information cannot be resolved, assessors can choose to leave a metric unrated—with explanation—as a last resort.

All metrics are worth 1 to 4 points. Some metrics (EX3, AC10) have submetrics. Each submetric is worth 2 points, and submetric scores are added together to get the overall metric score. Metrics may be assigned a range rating (e.g. low – moderate), particularly for exposure metrics, where groups or alliances are likely to span multiple ecoregions and exposure risks. Range ratings may also be assigned to adaptive capacity and threats metrics when there is considerable uncertainty.

Note that group ratings should not necessarily be averages of the ratings assigned to component alliances. Take for example hypothetical group X, made up of alliances A, B, and C. If alliances A, B, and C respectively get ratings of high, moderate, and low, the average rating would be moderate. However, if alliance C is far more common than the other two alliances, it is permissible for group X to be given a low rating.

2.4.2 Exposure (45% of Score)

Exposure may have multiple definitions when discussing climate change vulnerability. In this protocol, exposure refers to the modeled changes in climate variables that are related to a wetland's ecological integrity (as in Williams et al., 2008; Lyons et al., 2024).

Exposure metrics may be assessed with any climate model that depicts the variable in question—results will vary based on this decision. In initial applications, WNHP is using data extracted from the Washington Climate Impacts Group (WA CIG) Climate Mapping for a Resilient Washington's Climate Mapping Tool (Raymond & Rogers, 2022) by Stewart et al. (2024). WA CIG data is derived from the Coupled Intercomparison Project Phase 5 (CIMP5) models (Taylor et al., 2012). We chose to use the data from the Representative Concentration Pathway (RCP) 8.5, a "business as usual" emissions scenario that assumes continued increases in greenhouse gas emissions and no additional climate change mitigation (Thorne et al., 2016; Kerns et al., 2018; Halofsky et al., 2022). Data from WA CIG are presented as a percent change or a change in likelihood from modeled baseline conditions (1980 – 2009) to modeled future conditions (2070 – 2099), except for Summer Maximum Temperature (EX4), which is presented as change in °F. Only median values were provided in the initial data set we received. Baseline (1980 – 2009) or modeled future (2070 – 2099) measurements were not presented in the extracted WA CIG data. In future versions, we would like to include both the baseline exposure values and the range of modeled future values as well as the median data provided in this version. The WA CIG data is downscaled to a 2.5-minute resolution (Raymond & Rogers, 2022).

WNHP staff supplemented Total Annual Precipitation (EX1) and Summer Maximum Temperature (EX4) data with data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group, 2025) covering WNHP ecoregions and elevation bands. We used these data to determine the 1980 – 2009 baseline conditions and standard deviation of baseline data to create rating bins for these two metrics. PRISM data were not available for all of our exposure metrics.

Ideally, we would use spatially distributed plot data or mapping to extract exposure data for known occurrences of the ecosystem under consideration. However, existing wetland mapping for Washington is either too coarse to map most mid-scale wetland ecosystem types (e.g., USNVC Group Map, NatureServe, 2025) or does not contain enough relevant tabular data to confidently classify the USNVC ecosystem type present over a large proportion of the polygons (US Fish and Wildlife Service, 2024). Vegetation plots could be used in lieu of mapping if they were randomly distributed across the landscape, but existing plots are biased towards higher integrity occurrences on accessible public land.

Because of these limitations, we simply subset statewide climate data by ecoregion and elevation band (lowland or montane-subalpine) and assigned ratings based on the ecoregion/elevation combinations in which each USNVC group and alliance occurs. Since many groups and alliances span more than one ecoregion and/or elevation band, climate data and exposure ratings may be reported as ranges. Reporting ratings as a range is consistent with other CCVA methods. For example, CCVI 3.0 allowed reporting a range of scores for metrics where the available information was uncertain (Young et al., 2016).

The ecoregional system used by WNHP is modified from US Environmental Protection Agency (EPA) Level 3 ecoregions (Omernik & Griffith, 2014) to reflect local expertise and more precise boundaries (Figure 2). These modifications were made in consultation with multiple partners, particularly the Nature Conservancy and Washington Department of Fish and Wildlife (WADNR, 2022).

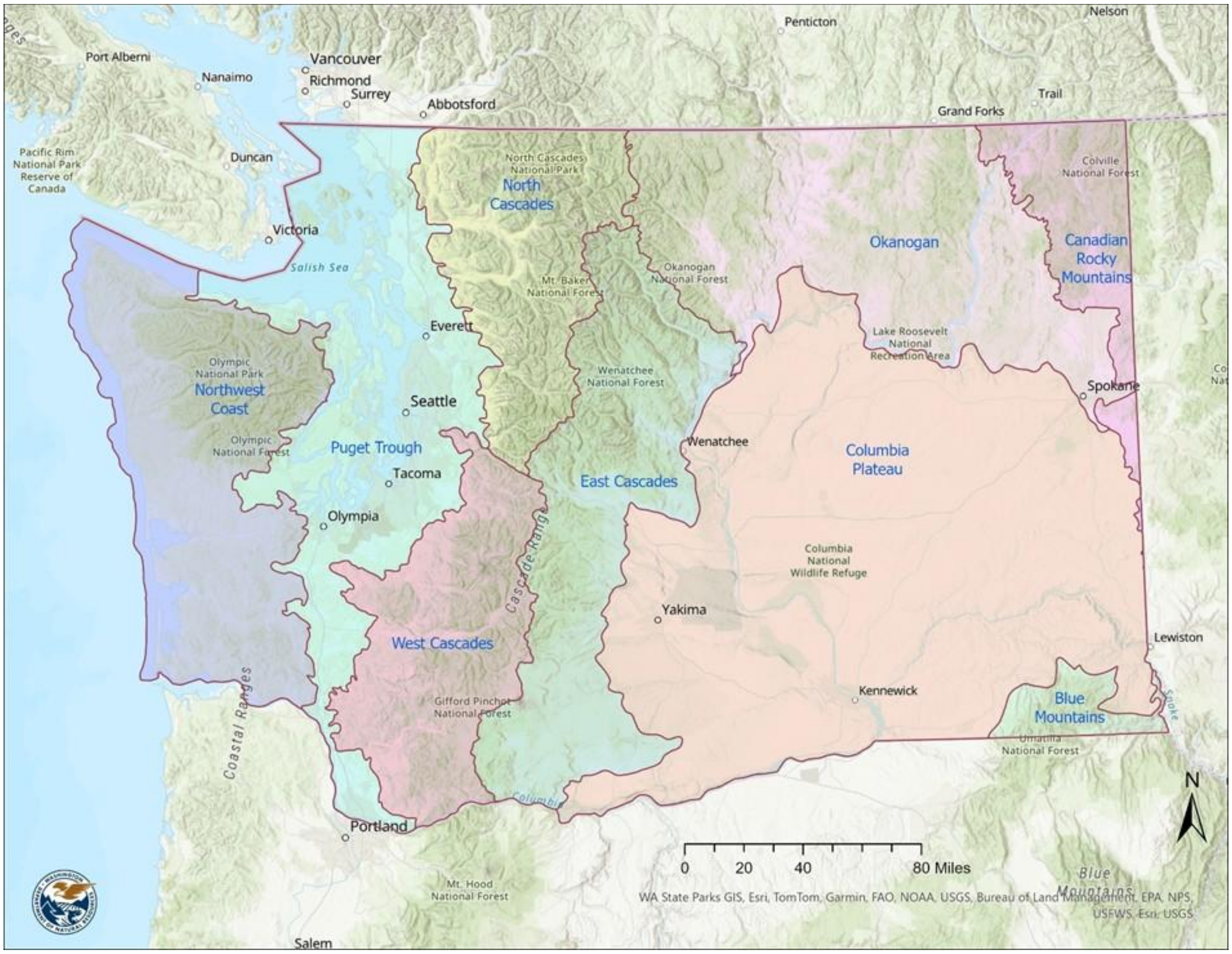

Figure 2. Ecoregions of Washington State.

Lowland and montane-subalpine elevation bands are divided at 1800 feet (~550 m), following the custom in Washington (e.g., Fonda & Bliss, 1969). In much of the state, this is the elevation above which non-transient winter snowpack develops. On the west side of the Cascades, this is also the approximate elevation at which the Western Hemlock (*Tsuga heterophylla*) zone begins transitioning to the Silver Fir (*Abies amabilis*) zone. East of the Cascades, upland trees are unlikely to be found below 1800 feet, though the contiguous lower treeline may be as high as 3000 feet on the margins of the Columbia Basin.

Quantitative values were divided into exposure ratings of Low, Moderate, High, and Very High. All exposure metrics except Summer Maximum Temperature (EX4) and Sea Level Rise (EX6) are presented as a percentage change or a change in likelihood from modeled baseline conditions. EX4 is presented as the modeled increase in °F and EX6 is evaluated by the percent of the ecosystem's range that could potentially be effected by sea level rise, following CCVI 4.0 methods (Lyons et al., 2024). The baseline period has been set as 1980 – 2009 and the model window predicts values for 2070 – 2099 for initial applications of this protocol. These periods may be adjusted in future versions of this protocol. While exposure metrics are rated and described separately, keep in mind that each of these metrics interact with one another.

When rating exposure metrics, consider the distribution and ecology of the group as a whole, do not average alliance scores to assign exposure ratings. Snowpack (EX3) is only rated if an alliance or group occurs above 1800 feet. Sea Level Rise (EX6) is only rated if the alliance or group has occurrences in areas affected by sea level rise. Groups are rated on their own merits. Group ratings are not rolled up from alliance ratings. In some cases, a group may not receive a rating for metrics EX3 or EX6 (= rated "NA") even if a component alliance within that group receives a rating. For example, one alliance within the North Pacific Open Bog & Acidic Fen Group occurs above 1800 feet and is rated as having very high vulnerability to changes in snowpack, but the majority of this group occurs at lower elevations where snowpack is not important to ecosystem processes, so the group as a whole received an NA rating for exposure to changes in snowpack (Appendix A).

When reporting exposure metrics, always include the climate models used. Exposure risks will change depending on the model.

EX1. Total Annual Precipitation
Definition: The percent decrease in yearly precipitation totals modeled for 2070 – 2099 compared to data from 1980 – 2009 (Stewart et al., 2024).

Background: Total annual precipitation is modeled to increase with climate change throughout Washington (Figure 3). However, this increase is not modeled to exceed natural variation until late in the century in the Pacific Northwest (Coops & Waring, 2011; Mauger et al., 2015) and in general modeled changes in total annual precipitation have high uncertainty (Mauger et al., 2015; Halofsky et al., 2020). Variation in historical precipitation data suggests that long-term trends may be obscured by historical variation in total annual precipitation (Abatzoglou et al., 2014).

Models suggest that increases in annual precipitation will be accompanied by change in precipitation patterns in the Pacific Northwest (Poff et al., 2002; Mauger et al., 2015; Halofsky et al., 2020). Though Washington already receives most of its rainfall outside the summer months, less summer rain, more rain in other seasons, and an increase in severity of atmospheric river events are likely with climate change (Mauger et al., 2015; Halofsky et al., 2020). Winter is modeled to see the greatest increases in precipitation, but there is a large range of variation in models (Elsner et al., 2010; Mote & Salathé, 2010). In many regions, including the Pacific Northwest, modeled increases in annual rainfall are not enough to counterbalance the negative effects of precipitation pattern shifts, increased average temperature, reduced snowpack, and increased likelihood of summer drought (Perry et al., 2012; Schneider, 2013; Thorne et al., 2016).

Models of total annual precipitation tend to have high uncertainty (Pitchford et al., 2012; Mauger et al., 2015; Halofsky et al., 2020) and some CCVA methods (e.g., Pitchford et al., 2012) do not use this variable. However, despite this uncertainty, we have included it because of the critical role that total precipitation plays in wetland ecological processes. Changes in precipitation amounts can shift hydrological balances, even in the absence of warming temperatures (Kolka et al., 2018).

Hydrology (Mauquoy & Yeloff, 2008; Rocchio & Ramm-Granberg, 2022), water balance (e.g., precipitation vs. evapotranspiration) (Mauquoy & Yeloff, 2008; Swanston et al., 2011; Closs et al., 2024), water chemistry (Poff et al., 2002; Rocchio et al., 2025), and disturbance regimes (Poff et al., 2002; Lawler & Mathias, 2007; Halofsky et al., 2020) can all be affected by changes in precipitation amounts. These variables are all important for development, structure, community composition, and resilience of wetland ecosystems.

For more background on the ecological importance of total annual precipitation, see Adaptive Capacity to Total Annual Precipitation (AC1).

Assessment Protocol: Baseline variability in climate data is important to consider when evaluating an ecosystem's exposure (Mote & Salathé, 2010). First, calculate the standard deviation of total precipitation in each ecoregion and elevation band for your baseline period. These values are the basis for this metric's rating bins. If the modeled change in total annual precipitation for the future period is within the range of natural variability for that ecoregion and elevation, than that change is less likely to be significant than if it is outside the range of natural variability (Girvetz et al., 2009).

Next, use the climate model of your choice to calculate the percent increase in total annual precipitation from the baseline period to the modeled period for each ecoregion and elevation band (see Figure 3 for an example). WNHP is using standard deviations calculated from PRISM records for total annual precipitation for the period 1980 – 2009 (PRISM Climate Group, 2025). These values are presented in Appendix B.

Use the following procedure to assign a metric rating.

1. Does the ecosystem occur in only one ecoregion and elevation band?

   Yes = Use the metric rating table (Table 2) to assign a rating.

   No = GO TO 2

2. Do all ecoregion/elevation combinations in which the ecosystem occurs fall within the same rating bin?

   Yes = Use the metric rating table (Table 2) to assign a rating.

   No = GO TO 3

3. Is the ecosystem roughly equally common in all ecoregion/elevation combinations in which it occurs? This can be determined using the ecosystem description or professional expertise.

   Yes = Assign a range rating spanning the range of ecoregions/elevation bands (e.g., High-Very High, Low-High, etc.). Range ratings have a point value equal to the midpoint of the range.

   No = GO TO 4

4. Use your expertise/judgement to assign a rating or range rating (Table 2) based on the ecoregion and elevation band combinations in which the ecosystem is most prevalent.

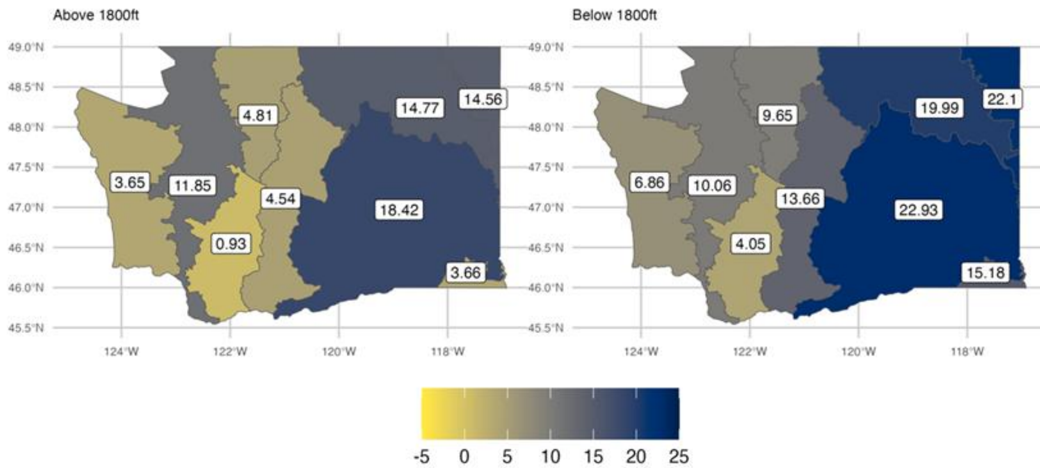

Figure 3. Modeled percent increase in Total Annual Precipitation (EX1) under future climate conditions (2070 – 2099) compared to baseline annual averages (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

Note that only precipitation <u>decreases</u> are considered within this metric. Any ecosystem experiencing precipitation <u>increases</u> will rate as having low exposure. Negative effects of increasing precipitation are largely covered in the subsequent metric (EX2. Extreme Precipitation Magnitude).

Table 2. Total Annual Precipitation (EX1) Metric Ratings.

Rating	Description	Points
Low Exposure	Modeled decrease in total annual precipitation is ≤ 1 standard deviation of the baseline period for the ecoregion and elevation band.	1
Moderate Exposure	Modeled decrease in total annual precipitation is > 1 standard deviation of the baseline period for the ecoregion and elevation band.	2
High Exposure	Modeled decrease in total annual precipitation is > 2 standard deviations of the baseline period for the ecoregion and elevation band.	3
Very High Exposure	Modeled decrease in total annual precipitation is > 3 standard deviations of the baseline period for the ecoregion and elevation band.	4

EX2. Extreme Precipitation Magnitude

Definition: The percent change in total precipitation received in one day (24 hours) during extreme precipitation events, modeled for 2070 – 2099 compared to data from 1980 – 2009 (Stewart et al., 2024). Extreme precipitation events are defined as the maximum daily precipitation that happens during a 25-year storm.

Background: In Washington, extreme precipitation events are modeled to increase in magnitude (Figure 4) (Halofsky et al., 2020), and atmospheric rivers are modeled to become more severe (Mauger et al., 2015). This is in part because a warmer atmosphere can hold more water (Trenberth, 2011). Increased magnitude of extreme precipitation events outside of summer months are the most likely mechanism by which total annual precipitation will increase in Washington (Mauger et al., 2015). Increases in the magnitude of precipitation events are related to increased temperatures, so increased magnitude of precipitation events are usually also associated with increases in potential evapotranspiration, resulting in larger water deficits and drier conditions overall even when precipitation amounts increase (Trenberth, 2011; Abatzoglou et al., 2014).

For more background on the ecological importance of extreme precipitation magnitude, see Adaptive Capacity to Extreme Precipitation Magnitude (AC2).

Assessment Protocol: First calculate baseline data for magnitude of extreme precipitation events in each ecoregion and elevation band for your baseline period. Also calculate the standard deviation of extreme precipitation magnitude for your baseline period if your data allows. Use standard deviation to calculate ratings bins if possible. For data sets that do not allow for calculating standard deviation, use quartiles to assign ratings bins, as in Comer et al. (2019).

Next, use the climate model of your choice to calculate the percent increase in the magnitude of extreme precipitation events from the baseline period to the modeled period for each ecoregion and elevation band. WNHP is using data from WA CIG's Climate Mapping for a Resilient Washington's Climate Mapping Tool (Raymond & Rogers, 2022) for Extreme Precipitation Magnitude. These data as provided to us do not include the necessary information to calculate standard deviation, so our ratings bins are presented as quartiles instead. This method is consistent with how other CCVA protocols assign ratings bins, including other NatureServe CCVA protocols (e.g., Comer et al., 2019).

Use the following procedure to assign a metric rating.

1. Does the ecosystem occur in only one ecoregion and elevation band?

   Yes = Use the metric rating table (Table 3) to assign a rating.

   No = GO TO 2

2. Do all ecoregion/elevation combinations in which the ecosystem occurs fall within the same rating bin?

   Yes = Use the metric rating table (Table 3) to assign a rating.

   No = GO TO 3

3. Is the ecosystem roughly equally common in all ecoregion/elevation combinations in which it occurs? This can be determined using the ecosystem description or professional expertise.

   Yes = Assign a range rating spanning the range of ecoregions/elevation bands (e.g., High-Very High, Low-High, etc.). Range ratings have a point value equal to the midpoint of the range.

   No = GO TO 4

4. Use your expertise/judgement to assign a rating or range rating (Table 3) based on the ecoregion and elevation band combinations in which the ecosystem is most prevalent.

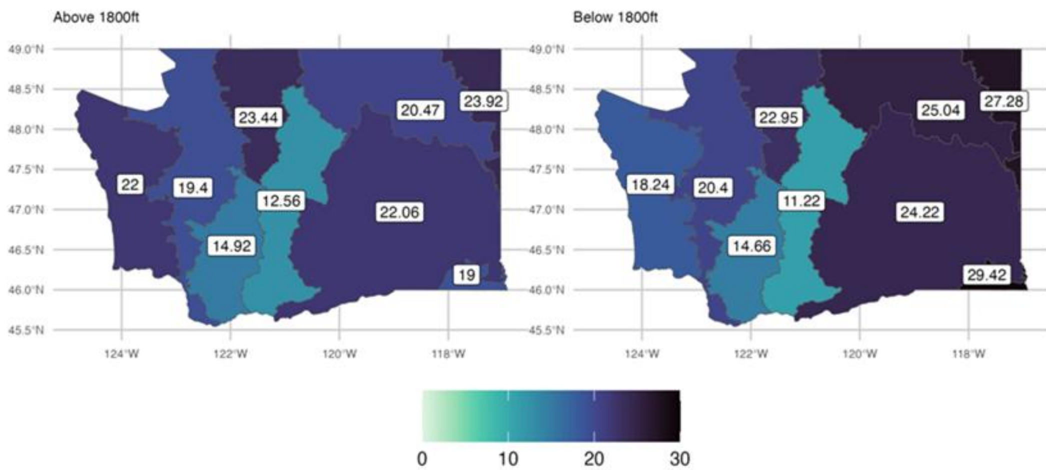

Figure 4. Modeled percent increase in Extreme Precipitation Magnitude (EX2) for 24 hours of extreme precipitation under future climate conditions (2070 – 2099) compared to baseline annual averages (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

Table 3. Extreme Precipitation Magnitude (EX2) Metric Ratings.

Rating	**Description**	**Points**
Low Exposure	Modeled percent change in magnitude of extreme precipitation events between baseline and future conditions is ≤ 25%.	1
Moderate Exposure	Modeled percent change in magnitude of extreme precipitation events between baseline and future conditions is 25 – 50%.	2
High Exposure	Modeled percent change magnitude of extreme precipitation events between baseline and future conditions is 50 – 75%.	3

Very High Exposure	Modeled percent change magnitude of extreme precipitation events between baseline and future conditions is > 75%.	4

EX3. Snowpack

Definition: Snowpack is divided into two submetrics, Snow Drought by April 1st (EX3.1), and Snowpack Change (EX3.2). EX3.1 models the likelihood that any year will have an April 1st snowpack below 75% of normal in 2070 – 2099 compared to data from 1980 – 2009 (Stewart et al., 2024). This submetric models, in part, the change in the propor of precipitation that falls as snow. EX3.2 models the percent change in the amount of water contained in the snowpack (snow water equivalent) on April 1st in 2070 – 2099 compared to data from 1980 – 2009 (Stewart et al., 2024). Taken together, these submetrics help estimate shifts in the proportion of winter precipitation falling as snow and the amount of water stored as snow at the end of the winter. April 1st is the standard date used to measure changes in snowpack and is important for predicting low water flows and available water later in the summer (Elsner et al., 2010; Flint et al., 2013; Krochta & Chang, 2024).

Background: Models suggest snowpack will be strongly affected by climate change in Washington, with large decreases in snowpack and increases in snow drought throughout the state. At least one source suggested that changes in snowpack may be the primary way that climate change affects the Pacific Northwest, particularly in the Cascades (Elsner et al., 2010). Globally, more precipitation is modeled to fall as rain instead of snow in northern regions due to climate change, especially at the beginning and end of the cold season (Trenberth, 2011). In Washington, snow droughts are modeled to increase in likelihood (Figure 5) and remaining snowpack on April 1st is modeled to decrease with climate change (Figure 6). The dates of last spring freeze and first autumn freeze have both shifted, increasing the frost free season by more than two weeks in the time span between 1972 – 2012 in Washington (Abatzoglou et al., 2014).

WA CIG and our maps also include snowpack data for ecoregions below 1800 feet elevation. Persistent snowpack does not develop in Washington at these elevations, so though 98 – 100% losses of snowpack are predicted for all ecoregions with data below 1800 feet (Stewart et al., 2024), we do not expect this change to be ecologically significant.

For more background on the ecological importance of snowpack, see Adaptive Capacity to Snowpack Change (AC3).

Assessment Protocol: Snowpack should only be rated for ecosystems that occur above 1800 feet. Watersheds where some or all of the basin occurs above the snow line will likely see shifts in peak flow and low flow due to changes in snowpack, but watersheds that occur entirely at lowland elevations (below 1800 feet) are likely not to be directly affected by changes in snowpack (Mauger et al., 2015). Therefore, ecosystems that occur only below 1800 feet are rated NA, and not scored for this metric.

SNOW DROUGHT BY APRIL 1ST: First calculate baseline data for snow drought by April 1st in each ecoregion that has data above 1800 feet for your baseline period. Also calculate the standard deviation of snow drought by April 1st for your baseline period, if your data allows. Use standard deviation to calculate ratings bins if possible. For data sets that do not allow for calculating standard deviation, use quartiles to assign ratings bins, as in Comer et al. (2019).

Next, use the climate model of your choice to calculate the percent increase in snow drought by April 1st from the baseline period to the modeled period for each ecoregion with data above 1800 feet. WNHP is using data from WA CIG's Climate Mapping for a Resilient Washington's Climate Mapping Tool (Raymond & Rogers, 2022) for all snowpack data. These data as provided to us do not include the necessary information to calculate standard deviation, so our ratings bins are presented as quartiles instead. This method is consistent with how other CCVA protocols assign ratings bins, including other NatureServe CCVA protocols (e.g., Comer et al., 2019).

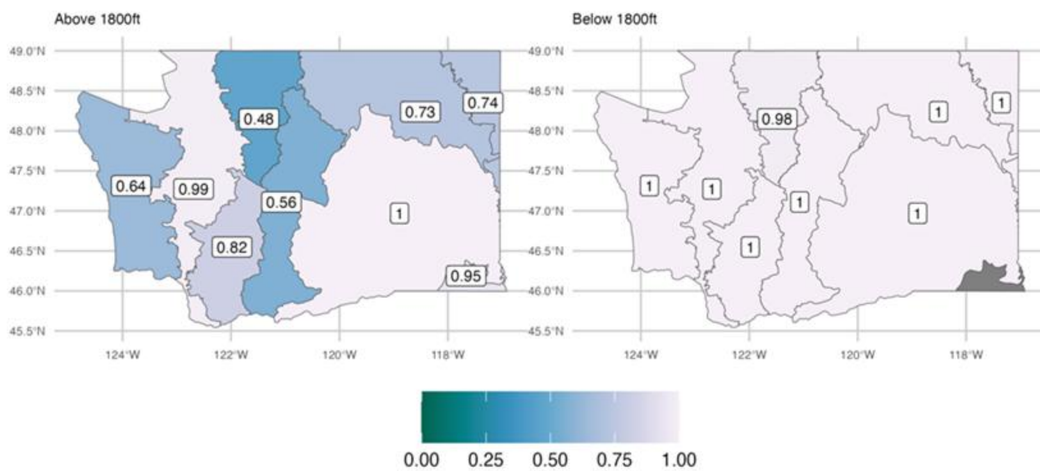

Figure 5. Modeled increase in Snow Drought by April 1st (EX3.1), as measured by snow received by April 1st is 75% or less than historical norms, under future climate conditions (2070 – 2099) compared to baseline conditions (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). The Blue Mountains ecoregion (in gray) does not have snow drought data below 1800 feet. These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

SNOWPACK CHANGE: First calculate baseline data for change in snowpack by April 1st in each ecoregion that has data above 1800 feet for your baseline period. Also calculate the standard deviation of change in snowpack for your baseline period, if your data allows. Use standard deviation to calculate ratings bins if possible. For data sets that do not allow for calculating standard deviation, use quartiles to assign ratings bins, as in Comer et al. (2019).

Next, use the climate model of your choice to calculate the percent change in snowpack April 1st from the baseline period to the modeled period for each ecoregion that has data above 1800. WNHP is using data from WA CIG's Climate Mapping for a Resilient Washington's Climate Mapping Tool (Raymond & Rogers, 2022) for all snowpack data. These data as provided to us do not include the necessary information to calculate standard deviation, so our ratings bins are presented as quartiles instead. This method is consistent with how other CCVA protocols assign ratings bins, including other NatureServe CCVA protocols (e.g., Comer et al., 2019).

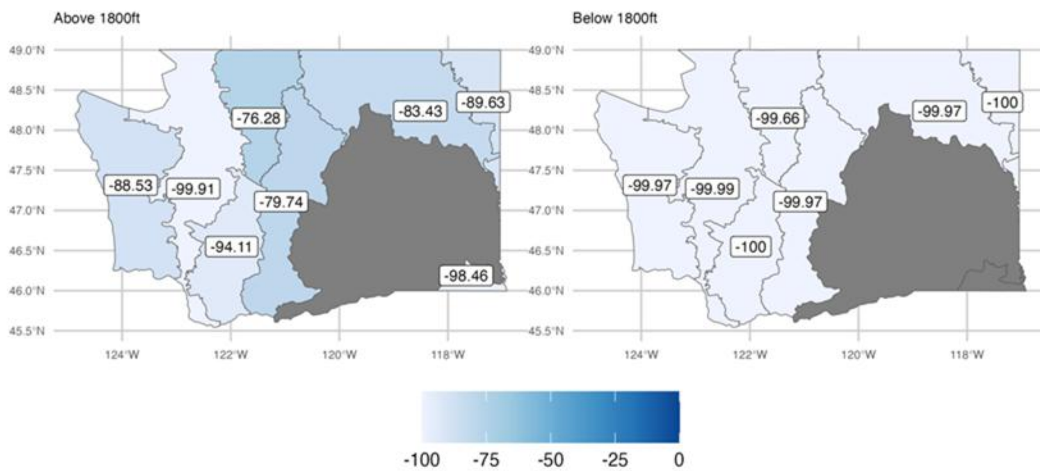

Figure 6. Modeled percent change for Snowpack Change (EX3.2), as measured by snow depth on April 1st, under future climate conditions (2070 – 2099) compared to baseline annual averages (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). Ecoregions in gray (Columbia Basin at all elevations, Blue Mountains below 1800 feet) do not have available observations for this metric. These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

Use the following procedure to assign a rating to both submetrics.

1. Does the ecosystem occur in only one ecoregion and elevation band?

   Yes = Use the metric rating table (Table 4) to assign a rating.

   No = GO TO 2

2. Do all ecoregion/elevation combinations in which the ecosystem occurs fall within the same rating bin?

   Yes = Use the metric rating table (Table 4) to assign a rating.

   No = GO TO 3

3. Is the ecosystem roughly equally common in all ecoregion/elevation combinations in which it occurs? This can be determined using the ecosystem description or professional expertise.

   Yes = Assign a range rating spanning the range of ecoregions/elevation bands (e.g., High-Very High, Low-High, etc.). Range ratings have a point value equal to the midpoint of the range.

   No = GO TO 4

4. Use your expertise/judgement to assign a rating or range rating (Table 4) based on the ecoregion and elevation band combinations in which the ecosystem is most prevalent.

The overall rating/score for the metric is determined by adding the two submetrics together.

Table 4. Snowpack (EX3) Metric Ratings.

Rating	Description	Points
Low Exposure	EX3.1) SNOW DROUGHT BY APRIL 1ST: Modeled increase in likelihood of snow drought by April 1st between baseline and future conditions is ≤ 25%.	0.5
	EX3.2) SNOWPACK CHANGE: Modeled decrease in snowpack on April 1st between baseline and future conditions is ≤ 25%.	0.5
Moderate Exposure	EX3.1) SNOW DROUGHT BY APRIL 1ST: Modeled increase in likelihood of snow drought by April 1st between baseline and future conditions is 25 – 50%.	1
	EX3.2) SNOWPACK CHANGE: Modeled decrease in snowpack on April 1st between baseline and future conditions is 25 – 50%.	1
High Exposure	EX3.1) SNOW DROUGHT BY APRIL 1ST: Modeled increase in likelihood of snow drought by April 1st between baseline and future conditions is 50 – 75%.	1.5
	EX3.2) SNOWPACK CHANGE: Modeled decrease in snowpack on April 1st between baseline and future conditions is 50 – 75%.	1.5
Very High Exposure	EX3.1) SNOW DROUGHT BY APRIL 1ST: Modeled increase in likelihood of snow drought by April 1st between baseline and future conditions is > 75%.	2
	EX3.2) SNOWPACK CHANGE: Modeled decrease in snowpack on April 1st between baseline and future conditions is > 75%.	2

EX4. Summer Maximum Temperature

Definition: The modeled change in maximum summer (June – August) temperature in °F in 2070 – 2099 compared to data from 1980 – 2009 (Stewart et al., 2024). Summer maximum temperature is presented °F rather than a percent change to ease interpretability.

Background: Essentially all changes in temperature due to climate change are likely to be increases (Girvetz et al., 2009). Latitude affects the amount of change, with northern temperate regions showing the greatest increases in temperature (Girvetz et al., 2009).

Maximum summer temperatures are modeled to increase throughout Washington, with slightly higher increases in eastern Washington than western Washington (Figure 7). There is disagreement between models, but most indicate that the greatest temperature changes in the Pacific Northwest will occur in the summer (Lawler & Mathias, 2007; Mote & Salathé, 2010; Halofsky et al., 2020, 2022). Extremes in temperature are modeled to increase more rapidly at high elevations, in complex terrain, and west of the Cascades (Salathé et al., 2023).

Models show warming trends accelerating, at least in the Pacific Northwest (Coops & Waring, 2011) and models suggest that maximum temperature will increase more than median temperature (Salathé et al., 2023). Extreme heat events are modeled to be more likely by 2100 (Heeter et al., 2023; Salathé et al., 2023). A study using tree ring data and climate models suggest that risk of incidents like the 2021 heat dome could increase by 94% by 2100 in the Pacific Northwest (Heeter et al., 2023). The 2021 heat dome was previously a one in 1000 year event, and anthropogenic climate change is modeled to increase the possibility of heat domes like 2021 reoccurring (Heeter et al., 2023). Temperatures that increase beyond historical range of variability are most dangerous because they are likely to exceed the adaptive capacity of the existing ecosystem (Salathé et al., 2023).

For more background on the ecological importance of maximum summer temperatures, see Adaptive Capacity to Summer Maximum Temperature (AC4).

Assessment Protocol: First, calculate the standard deviation of summer maximum temperature in each ecoregion and elevation band for your baseline period. These values are the basis for this metric's rating bins. If the modeled change in total annual precipitation for the future period is within the range of natural variability for that ecoregion and elevation, than that change is less likely to be significant than if it is outside the range of natural variability (Girvetz et al., 2009).

Next, use the climate model of your choice to calculate the increase in summer maximum temperatures from the baseline period to the modeled period for each ecoregion and elevation band (see Figure 7 for an example). WNHP is using standard deviations calculated from PRISM records for summer maximum temperature for the period 1980 – 2009 (PRISM Climate Group, 2025). These values are presented in Appendix B. Notably, the very high exposure bin (> 3 SD) approximates the extreme temperatures already experienced in the Pacific Northwest during the 2021 heat dome event (Reyes & Kramer, 2023).

Use the following procedure to assign a metric rating.

1. Does the ecosystem occur in only one ecoregion and elevation band?

   Yes = Use the metric rating table (Table 5) to assign a rating.

   No = GO TO 2

2. Do all ecoregion/elevation combinations in which the ecosystem occurs fall within the same rating bin?

   Yes = Use the metric rating table (Table 5) to assign a rating.

   No = GO TO 3

3. Is the ecosystem roughly equally common in all ecoregion/elevation combinations in which it occurs? This can be determined using the ecosystem description or professional expertise.

   Yes = Assign a range rating spanning the range of ecoregions/elevation bands (e.g., High-Very High, Low-High, etc.). Range ratings have a point value equal to the midpoint of the range.

   No = GO TO 4

4. Use your expertise/judgement to assign a rating or range rating (Table 5) based on the ecoregion and elevation band combinations in which the ecosystem is most prevalent.

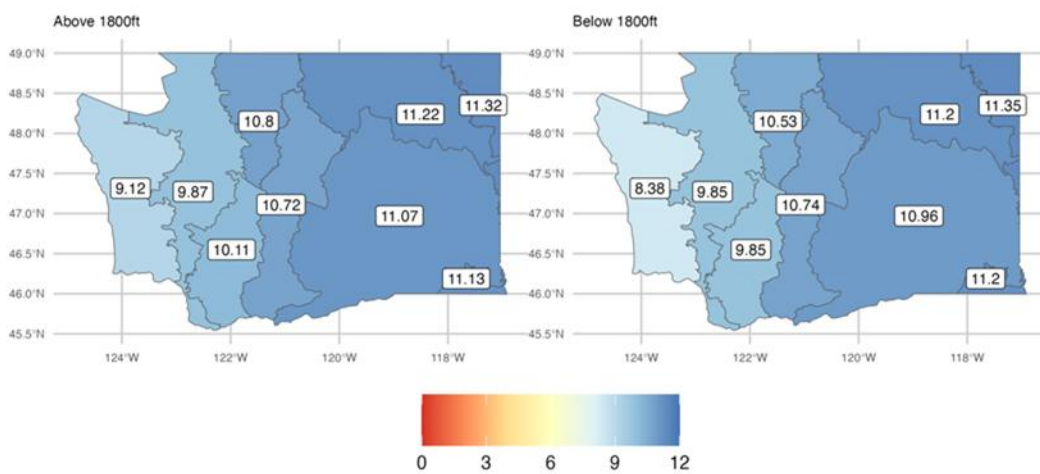

Figure 7. Modeled increase in temperature in °F in Summer Maximum Temperature (EX4) under future conditions (2070 – 2099) compared to baseline conditions (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

Table 5. Summer Maximum Temperature (EX4) Metric Ratings.

Rating	**Description**	**Points**
Low Exposure	Modeled increase in maximum summer temperature is ≤ 1 standard deviation of the baseline period for the ecoregion and elevation band.	1
Moderate Exposure	Modeled increase in maximum summer temperature is > 1 standard deviation of the baseline period for the ecoregion and elevation band.	2
High Exposure	Modeled increase in maximum summer temperature is > 2 standard deviations of the baseline period for the ecoregion and elevation band.	3

Very High Exposure	Modeled increase in maximum summer temperature is > 3 standard deviations of the baseline period for the ecoregion and elevation band.	4

EX5. Precipitation Drought in Summer

Definition: The percent chance that any year within the 2070 – 2099 time period will experience less than 75% of the baseline (1980 – 2009) average precipitation for June – August (Stewart et al., 2024).

Background: The likelihood of summer drought conditions is modeled to increase throughout Washington, with the greatest increase in western Washington (Figure 8) (Halofsky et al., 2020). Models of precipitation patterns have substantial uncertainty, but nearly all of them agree that the Pacific Northwest will see a decrease in summer precipitation (Lawler & Mathias, 2007; Mote & Salathé, 2010; Mauger et al., 2015). Most precipitation in Washington already occurs in winter (Mote & Salathé, 2010; Perry et al., 2012), with less than 10% of annual precipitation falling during the summer months (Mauger et al., 2015). However, reductions in summer precipitation can still have negative effects on hydrology and available water in Washington's wetlands (Mauger et al., 2015). Increased evapotranspiration coupled with decreased summer and fall precipitation has already increased water deficits in the Pacific Northwest, for a loss of ~20 mm/decade for 1980 – 2012 (Abatzoglou et al., 2014).

For more background on the ecological importance of precipitation droughts in summer, see Adaptive Capacity to Precipitation Drought in Summer (AC5).

Assessment Protocol: First calculate baseline data for precipitation drought in summer in each ecoregion and elevation band for your baseline period. Also calculate the standard deviation of precipitation drought in summer for your baseline period if your data allows. Use standard deviation to calculate ratings bins if possible. For data sets that do not allow for calculating standard deviation, use quartiles to assign ratings bins, as in Comer et al. (2019).

Next, use the climate model of your choice to calculate the percent increase in the magnitude of extreme precipitation events from the baseline period to the modeled period for each ecoregion and elevation band. WNHP is using data from WA CIG's Climate Mapping for a Resilient Washington's Climate Mapping Tool (Raymond & Rogers, 2022) for Precipitation Drought in Summer. These data do not include the necessary information to calculate standard deviation, so our ratings bins are presented as quartiles instead. This method is consistent with how other CCVA protocols assign ratings bins, including other NatureServe CCVA protocols (e.g., Comer et al., 2019).

Use the following procedure to assign a metric rating.

1. Does the ecosystem occur in only one ecoregion and elevation band?

   Yes = Use the metric rating table (Table 6) to assign a rating.

   No = GO TO 2

2. Do all ecoregion/elevation combinations in which the ecosystem occurs fall within the same rating bin?

   Yes = Use the metric rating table (Table 6) to assign a rating.

   No = GO TO 3

3. Is the ecosystem roughly equally common in all ecoregion/elevation combinations in which it occurs? This can be determined using the ecosystem description or professional expertise.

   Yes = Assign a range rating spanning the range of ecoregions/elevation bands (e.g., High-Very High, Low-High, etc.). Range ratings have a point value equal to the midpoint of the range.

   No = GO TO 4

4. Use your expertise/judgement to assign a rating or range rating (Table 6) based on the ecoregion and elevation band combinations in which the ecosystem is most prevalent.

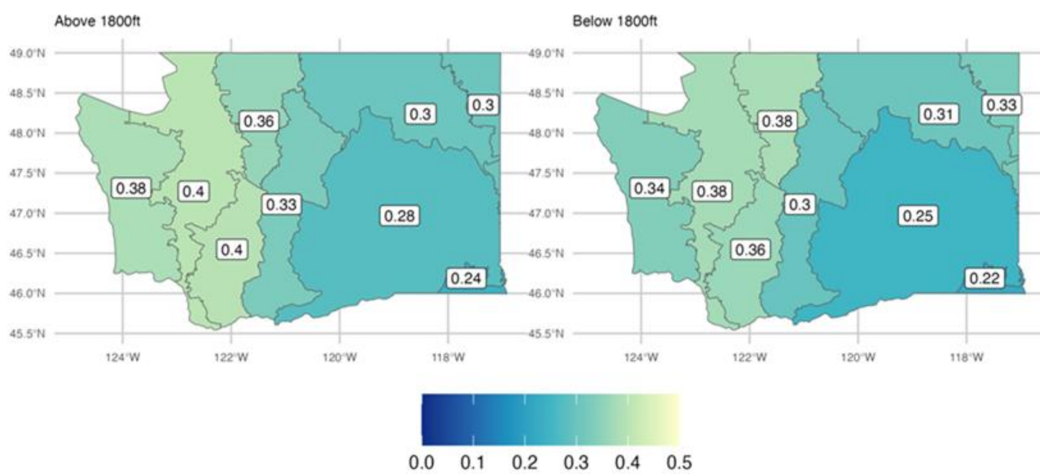

Figure 8. Modeled increase in Precipitation Drought in Summer (EX5) under future climate conditions (2070 – 2099) compared to baseline conditions (1980 – 2009) by ecoregion (Raymond & Rogers, 2022). These data are derived from CIMP5 models using RCP 8.5 (Taylor et al., 2012). Map created by Anthony J. Stewart.

Table 6. Precipitation Drought in Summer (EX5) Metric Ratings.

Rating	Description	Points
Low Exposure	Modeled likelihood of increase in precipitation drought from June – August between baseline and future conditions is ≤ 25%	1

Moderate Exposure	Modeled likelihood of increase in precipitation drought from June – August between baseline and future conditions is 25 – 50%	2
High Exposure	Modeled likelihood of increase in precipitation drought from June – August between baseline and future conditions is 50 – 75%	3
Very High Exposure	Modeled likelihood of increase in precipitation drought from June - August between baseline and future conditions is > 75%	4

EX6. Sea Level Rise

Definition: The percent of an ecosystem's range that occurs in coastal areas exposed to potential increases in sea level, as in CCVI 4.0 (Lyons et al., 2024).

Background: Salt marshes are predicted to increase and freshwater tidal marshes are predicted to decrease in area due to sea level rise in Washington (Mauger et al., 2015). In the Puget Sound, sea level rise is likely to track global estimates (Mote & Salathé, 2010). Uplift on the northern Olympic Peninsula and Washington Coast will reduce the effects of sea level rise in these regions (Mote & Salathé, 2010; Parker & Boyer, 2019). However, models of sea level rise have substantial uncertainty because the potential effects of melting ice sheets in Greenland and Antarctica are not well known (Mote & Salathé, 2010).

For more background on the ecological importance of sea level rise, see Adaptive Capacity to Sea Level Rise (AC6).

Assessment Protocol: This metric is only rated if an ecosystem occurs at low elevations of coastal ecoregions that may theoretically be affected by sea level rise. Ecosystems that are entirely inland will receive an NA rating.

Exposure is rated using the percentage of an ecosystem's range that may be subject to sea level rise (Table 7). Use ecological information, spatial and other data on ecosystem locations, and professional expertise to determine if an ecosystem needs to be rated for exposure to sea level rise. Areas in Washington affected by sea level rise can be can be visualized using The National Oceanic and Atmospheric Administration (NOAA)'s Sea Level Rise Viewer tool (NOAA, 2025), or through the Climate Mapping for a Resilient Washington's Climate Mapping Tool, using the Likely Sea Level Rise Climate Indicator, which maps areas with a 50% chance of being affected by sea level rise in Washington State (Raymond & Rogers, 2022).

Use the following procedure to assign a metric rating.

1. Does this ecosystem occur in areas likely to be affected by sea level rise? (use maps/descriptions/professional expertise to evaluate this)

    Yes = GO TO 2

    No = Rate as NA

2. Does this ecosystem occur in areas likely to be affected by sea level rise? (Use maps, writing descriptions and professional expertise to evaluate this.)

   Yes = Use the metric rating table (Table 7) to assign a rating.

   No = Rate as NA

Table 7. Sea Level Rise (EX6) Metric Ratings.

Rating	Description	Points
Low Exposure	<10% of range occurs in area subject to sea level rise.	1
Moderate Exposure	10-49% of range occurs in area subject to sea level rise	2
High Exposure	50-90% of range occurs in area subject to sea level rise.	3
Very High Exposure	>90% of range occurs in area subject to sea level rise.	4

2.4.3 Adaptive Capacity (45% of Score)

Adaptive capacity is defined as the natural characteristics that allow an ecosystem to adapt and respond to changes in climate exposure (Comer et al., 2019). Many climate change vulnerability analysis methods consider adaptive capacity and sensitivity as separate attributes, but in our review, we found sensitivity to be frequently defined by a species or ecosystem's adaptive capacity or as the response mediated by a species or ecosystem's adaptive capacity (e.g., Williams et al., 2008; Thorne et al., 2016; Defne et al., 2020; Halofsky et al., 2022). In order to avoid redundant metrics, we considered ecosystem sensitivity as part of our Adaptive Capacity metrics instead of as a separate section.

In this protocol, adaptive capacity metrics generally involve qualitative ratings based on literature review and professional expertise. Adaptive capacity is considered separately from exposure ratings. For the metrics in this section, evaluate how an ecosystem may or may not adapt to a shift from baseline climate exposures. Where exposure asks how climate variables might change, adaptive capacity asks what happens to an ecosystem if climate variables change. An ecosystem with low vulnerability (very high adaptive capacity) is one that experiences very little impact from shifts in an exposure variable, and generally maintains its characteristic composition, structure, and processes even when exposed to climate change. An ecosystem with very high vulnerability (low adaptive capacity) on the other hand is unable to adapt to shifts in climate exposure and is very likely to be eliminated or experience significant shifts in its attributes when exposed to climate change.

When evaluating an ecosystem's adaptive capacity and sensitivity, it is useful to consider what the limiting ecological characteristics are for that ecosystem (e.g., temperature, water availability), (Littell et al., 2010; Kerns et al., 2018). Magnitude of natural variations in climate metrics are also important to consider (Girvetz et al., 2009).

Adaptive Capacity metrics fall into three categories in this protocol: Abiotic Factors and Climate Niche; Distribution and Range; and Diversity, Community Structure, and Community Dynamics. This approach was adapted from Thurman et al. (2020) and NatureServe's CCVI 4.0 protocol (Lyons et al., 2024). These are both species-level assessments with adaptive capacity divided into seven categories: distribution, movement, evolutionary potential, ecological role, abiotic niche, life history, and demography (Thurman et al., 2020; Lyons et al., 2024). While several of these categories are not relevant to ecosystems (e.g., life history), others have ecosystem equivalents.

Where possible, metric ratings and methods align with pre-existing protocols, such as CCVI 4.0 (Lyons et al., 2024), NatureServe's Habitat Climate Change Vulnerability Index (HCCVI) protocol (Comer et al., 2019), or WNHP's Wetland Ecological Integrity Assessment (EIA) protocol (Rocchio et al., 2024).

To keep scoring and rating labels similar between categories, adaptive capacity ratings use a scale of low vulnerability to very high vulnerability. As in the exposure and threats sections, a low rating indicates low vulnerability to climate change, meaning the assessed ecosystem has high adaptive capacity. A high score indicates high vulnerability to climate change, meaning an ecosystem has low adaptive capacity.

When rating these metrics, consider the distribution and ecology of the group as a whole, do not average alliance scores to assign adaptive capacity ratings to the group. Adaptive Capacity to Snowpack Change (AC3) and Adaptive Capacity to Sea Level Rise (AC6) are only rated if the alliance or group was also rated for Snowpack (EX3) and Sea Level Rise (EX6). As with exposure, groups can be rated NA for these two metrics even if some of their alliances receive vulnerability ratings for the same metric. Adaptive capacity metrics are reported separately for alliance and group.

Abiotic Factors and Climate Niche

This section evaluates an ecosystem's ability to respond to changes in abiotic and climatic variables due to climate change. The ecosystem's direct responses to exposure variables are documented here. The importance of specific hydrological conditions and biophysical settings and how they contribute to an ecosystem's adaptive capacity are also evaluated in this section.

AC1. Adaptive Capacity to Total Annual Precipitation

Definition: An ecosystem's ability to adapt to decreases in total annual precipitation due to climate change.

Background: We focused on decreases in total annual precipitation for this metric because increases in total annual precipitation are likely to have no effect or positive effects on most wetland ecosystems in Washington. Increased precipitation can also potentially change ecosystem type, structure and/or species composition (e.g., a water influx can shift a peatland ecosystem to a marsh (Rocchio & Ramm-Granberg, 2022)). However, increases in total annual precipitation are not likely to be enough to affect water tables in Washington on their own.

Changes in total annual precipitation, particularly decreases, can significantly affect abiotic conditions and ecological processes in wetlands. The balance of precipitation and evapotranspiration is important for the formation and continued persistence of wetland ecosystems (Rigg, 1925; Cai & Yu, 2011; Closs et al., 2024). Decreases in precipitation can result in lower water tables including permanent wetlands becoming ephemeral or ephemeral wetlands disappearing (Lee et al., 2015; Halabisky et al., 2017). For example, shifts in water balance can change community composition in peatlands towards more vascular plants and allow forest expansion into peatlands (Rigg, 1925; Mauquoy & Yeloff, 2008; Cai & Yu, 2011). This happens in part because changes in precipitation volume has the potential to change the underlying hydrological conditions. Wetlands with hydrology dependent on precipitation are likely most vulnerable to decreases in total annual precipitation. Changes in hydrological regime, particularly lowered water tables or increased fluctuation in water tables, can also increase decomposition and carbon loss in wetlands (Bridgham et al., 2008; Tahvanainen, 2011). Changes in decomposition dynamics can change community structure and composition.

Decreases in precipitation amounts are likely to result in increases of drought tolerant species in wetland ecosystems (e.g., introduced species like *Acer negundo*, *Tamarix* spp., and *Elaeagnus angustifolia* in Washington's riparian wetlands) (Kominoski et al., 2013). Change in species composition can also lead to change in organic inputs in an ecosystem (Kominoski et al., 2013), which in turn might push the ecosystem further from naturally occurring conditions. Reduction in precipitation can also affect salinity in tidal marshes, as can changes in freshwater inputs from stream or river flow (Brinson, 1993).

Changes in precipitation amounts can also change disturbance regimes. Relatively small changes in precipitation can have large effects on flooding (Lawler & Mathias, 2007). Evidence from the Mississippi River Basin found that increases in precipitation by 10 – 20%, accompanied by increases in temperature of 1 – 2 ºC, caused significant increases in flood magnitude and frequency. Shifts in flood frequency can alter community and ecosystem structure and type (Poff et al., 2002). Decreases in precipitation can increase amount of area burned in wildfires (Halofsky et al., 2022). While wetlands are often fire refugia, there may still be indirect effects (e.g., influx of nutrients into wetlands, changes to water tables) and some wetlands with relatively ephemeral hydrological regimes may readily burn (Markle et al., 2022; Jones et al., 2024; Li et al., 2024).

Assessment Protocol: This metric considers decreases to the amount of precipitation an ecosystem receives. Changes to the pattern or type of precipitation is evaluated in Adaptive Capacity to Extreme Precipitation Events (AC2), Adaptive Capacity to Snowpack Changes (AC3), and Adaptive Capacity to Precipitation Drought in Summer (AC5). Using professional expertise and relevant literature review, choose the best option from Table 8. This metric addresses how well an ecosystem may adapt to decreases in precipitation.

Consider what abiotic processes may be impacted by decreases in precipitation. Do you expect those impacts to shift ecological processes, community composition, or ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of decreased precipitation? For example, ecosystems that depend on precipitation alone for their water source could be particularly vulnerable to reductions in precipitation, especially if that ecosystem also requires a stable water table. Ecosystems that are adapted to extended dry periods may have greater adaptive capacity to changes in precipitation patterns, but professional expertise and relevant literature should be used to support any assumptions of low vulnerability (high adaptive capacity) to changes in precipitation patterns for these communities.

Table 8. Adaptive Capacity to Total Annual Precipitation (AC1) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Decrease in total annual precipitation has little to no impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • The ecosystem is fed by a stable water source that does not rely on precipitation. • The ecosystem is adapted to dry periods (e.g., vernal pools).	1
Moderate Vulnerability (=High Adaptive Capacity)	Decrease in total annual precipitation has low impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	2
High Vulnerability (=Moderate Adaptive Capacity)	Decrease in total annual precipitation has moderate impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	3
Very High Vulnerability (=Low Adaptive Capacity)	Decrease in total annual precipitation has significant impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • Wetlands that require precipitation to exceed evapotranspiration to persist (e.g., peatlands). • At least some of the alliances in the group rely on precipitation alone for their water source. • Decreases in precipitation could cause a shift in ecosystem type (e.g., peatland to marsh, vernal pool to upland grassland).	4

AC2. Adaptive Capacity to Extreme Precipitation Magnitude

Definition: An ecosystem's adaptive capacity to an increase in the magnitude of extreme precipitation events due to climate change. This metric considers the effects of an increase in the amount of precipitation arriving in individual 24-hour events.

Background: Precipitation patterns are important for understanding how precipitation can affect wetland ecosystem dynamics. An increase in precipitation arriving as part of extreme rainfall events leads to more runoff and flooding and dryer soil conditions than under baseline conditions (Trenberth, 2011). Changes in seasonality and patterns of precipitation and runoff are likely to affect hydrological conditions and can increase fluctuation of water tables (Poff et al., 2002; Barel et al., 2021), shift ecological processes such as decomposition rates (Bridgham et al., 2008), and potentially change the structure or type of the ecosystem.

Increases in extreme precipitation events change the timing and pattern of floods, affecting geomorphological processes that help structure ecosystems (Perry et al., 2012). Extreme precipitation can lead to increased erosion (Renou-Wilson & Wilson, 2018). Changes in flood patterns will affect floodplain wetlands, potentially disconnecting their hydrology from other systems, especially along rivers where snowmelt runoff is important (Poff et al., 2002). However, increased river flows and sediment movement could be beneficial for coastal ecosystems by mitigating sea level rise (Day et al., 2008), assuming sediment from flooding events makes it into coastal ecosystems. Substrate can mitigate or intensify the effects runoff. Areas with more porous substrates will have reduced runoff and increased water storage (Flint et al., 2013). Changes in disturbance patterns can also change community composition, structure, and patch dynamics (Perry et al., 2012; Kominoski et al., 2013; Halofsky et al., 2020). For example, floods are important for seed dispersal and establishment of riparian species (e.g., cottonwood species) (Poff et al., 2002; Perry et al., 2012).

Changes in precipitation amounts can also affect water and soil pH in wetlands, as well as nutrient and pollutant inflows (Mauquoy & Yeloff, 2008; Pitchford et al., 2012; Rocchio et al., 2025). Increased rainfall can increase influx of outside nutrients, pollutants, and sediments, which can change pH and available nutrients, which can in turn change ecosystem composition (e.g., favoring plants that benefit from increased nutrients over plants that thrive in low nutrient environments or changing symbiotic relationships between vegetation and soil communities) (Poff et al., 2002; Mauquoy & Yeloff, 2008; Perry et al., 2012; Hedwall et al., 2017; Rocchio et al., 2024). For example, stormwater influxes have been shown to elevate pH levels in Puget Lowland peatlands, (Rocchio et al., 2025) and increases in nitrogen can reduce *Sphagnum* abundance (Hedwall et al., 2017).

Drought and strong rainfall events appear to be coupled, and increases in extreme rainfall events are also associated with increases in summer drought (Seavy et al., 2009; Trenberth, 2011). The combination of drought and extreme precipitation could favor vascular plants in peatlands (Barel et al., 2021). Streamflow changes can also interact with drought, making riparian areas more vulnerable to changes in hydrology due to climate change (Perry et al., 2012).

Assessment Protocol: This metric evaluates the effects of increases in magnitude of precipitation events. Changes in total annual precipitation are considered in Adaptive Capacity to Total Annual Precipitation (AC1), and changes in type or timing of precipitation are considered in Adaptive Capacity to Snowpack Changes (AC3) and Adaptive Capacity to Precipitation Drought in Summer (AC5).

Using professional expertise and relevant literature review, choose the best option from Table 9. This metric addresses how vulnerable an ecosystem is to increases in the size and/or frequency of extreme precipitation events. (Note that the exposure data WNHP is using only models changes in magnitude of extreme precipitation events, not changes in frequency). The effects of flooding should also be considered under this metric. Consider what abiotic processes increased extreme precipitation magnitude might impact in the ecosystem. Do you expect those impacts to shift ecological processes, community composition, or ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of increased extreme precipitation magnitude?

Table 9. Adaptive Capacity to Extreme Precipitation Magnitude (AC2) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Extreme precipitation events have little to no impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • An ecosystem has a water source that remains stable under changing precipitation patterns. • An ecosystem is resilient to changes in inputs or flood disturbance patterns.	1
Moderate Vulnerability (=High Adaptive Capacity)	Extreme precipitation events have low impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	2
High Vulnerability (=Moderate Adaptive Capacity)	Extreme precipitation events have moderate impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	3
Very High Vulnerability (=Low Adaptive Capacity)	Extreme precipitation events have significant impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	4

AC3. Adaptive Capacity to Snowpack Change

Definition: An ecosystem's adaptive capacity to decreases in the amount of precipitation that falls as snow and shifts in the timing of spring snowmelt.

Background: Snowpack is important because it provides water late in the season when water deficits elsewhere are the greatest, particularly in arid ecosystems which may rely on snowmelt for most of their water (Brinson, 1993; Halofsky et al., 2022; Reyes & Kramer, 2023). Abundance and persistence of snowpack is affected by temperature, particularly in the winter and spring (Girvetz et al., 2009; Reyes & Kramer, 2023). Earlier snowmelt dates in the northern hemisphere are correlated with heat waves, increases in drought, and decreases in summer precipitation (Trenberth, 2011; Liu et al., 2024). Snowpack is an important water source for montane and subalpine ecosystems in Washington, and snow drought means less water available for ecosystems in the summer, intensifying the effects of summer drought and heat waves (Trenberth, 2011; Reyes & Kramer, 2023; Liu et al., 2024).

Ecosystems and species with snowpack-dependent hydrology have increased vulnerability to climate change (Lee et al., 2015). Reduced snowpack could lead wetlands to dry out earlier (Lee et al., 2015). Less snowpack and earlier snowmelt dates can lead to less water infiltration, meaning less recharge of groundwater (Trenberth, 2011; Flint et al., 2013) and a reduction of late season water flows (Halofsky et al., 2022). Ephemeral montane and subalpine wetlands could also disappear, and permanent wetlands could become ephemeral, though these changes will be mediated by a wetland's dominant water source (Lee et al., 2015). These changes in hydrology are likely to change the composition and structure of vegetation communities in these wetlands (Poff et al., 2002). Loss of permanent water will also affect animals that rely on permanent wetlands for at least one life stage (Lee et al., 2015).

Loss of snowpack can also have larger climate effects, including indirect effects on neighboring regions (Liu et al., 2024). Short snow seasons and low snowpack increases surface heat and reduces soil moisture (Liu et al., 2024). Low soil moisture can reduce evaporative cooling and cloud formation, leading to precipitation reductions at local and regional levels (Liu et al., 2024). These effects can reduce freshwater availability, and increase likelihood of summer droughts, heat waves, and wildfires, as well as cause reduced productivity in vegetation communities (Trenberth, 2011; Halofsky et al., 2020; Reyes & Kramer, 2023; Liu et al., 2024).

Reduced snowpack and earlier snowmelt may also change timing and intensity of flooding (Lawler & Mathias, 2007). Warm springs and shortened snow seasons can increase early season runoff, but snow-droughts will reduce runoff (Liu et al., 2024). In the Pacific Northwest, warmer spring temperatures can result in earlier snowmelt dates, regardless of amount of precipitation that falls as snow in the winter (Maher & Veldhuisen, 2023; Reyes & Kramer, 2023; Whitfield et al., 2024). Evidence suggests that more precipitation is falling as rain instead of snow, spring conditions have started arriving earlier, and rainfall season has increased by up to three weeks in some boreal areas (Trenberth, 2011). Increases in winter precipitation are more likely to be due to rain and not snow in Washington, reducing stored water and decreasing groundwater recharge and water flows in late summer (Poff et al., 2002). Reduced freshwater stream and river flows can also affect salinity in tidal marshes (Brinson, 1993). Earlier snowmelt contributes to earlier drying of wetlands, particularly at high elevations where hydrology might depend on late season snowmelt (Lee et al., 2015). The resulting changes in flood patterns can potentially disconnect floodplain wetlands hydrology from other systems, especially along rivers where snowmelt runoff is important (Poff et al., 2002). Changes in the timing and intensity of spring runoff could also disrupt other geomorphological processes as well as nutrient inputs for associated wetlands (Perry et al., 2012).

Major floods are associated with rain on snow in the Pacific Northwest (Franklin et al., 1991). This is a phenomenon of areas that get large amounts of snow but also can expect warm, wet air masses from the ocean in the winter (Franklin et al., 1991). Larger floods also result in lower infiltration and more water lost to runoff (Trenberth, 2011). Changes in snowmelt runoff, including earlier flooding, can also disrupt nutrient, disturbance and even seed dispersal dynamics downstream (Poff et al., 2002; Perry et al., 2012). Summer drought and early snowmelt are closely related to developing wildfire conditions in the Pacific Northwest (Halofsky et al., 2020). While wetlands are generally regarded as refugia from fire, some wetlands, particularly ephemeral wetlands, may experience direct effects from wildfires.

Assessment protocol: This metric evaluates the effects of decreased snowpack and earlier snowmelt dates on wetland ecosystems. Using professional expertise and relevant literature review, choose the best option from Table 10. Changes to precipitation patterns and amounts are also evaluated in Adaptive Capacity to Total Annual Precipitation (AC1), Adaptive Capacity to Extreme Precipitation Events (AC2), and Adaptive Capacity to Precipitation Drought in Summer (AC5).

Ecosystems that occur primarily below 1800 feet should be rated NA for this metric. While snow does occur below 1800 feet in Washington, it rarely forms a snowpack. Changes in amount of precipitation that occurs as snow at lowland elevations is not likely to have direct effects on an ecosystem's climate change exposure.

Consider potential abiotic processes impacted by decreases in snowpack. Are impacts expected to shift ecological processes, community composition, or the ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of decreased snowpack? For example, ecosystems that get the majority of their water from snowpack, or have several key species that are dependent on snowpack, are likely more vulnerable (have less adaptive capacity) to changes in snowpack. When considering adaptive capacity for this metric, effects of drought, wildfire, and changes in timing of spring runoff may also be noted (Liu et al., 2024).

Table 10. Adaptive Capacity to Snowpack Change (AC3) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Change in snowpack has little to no impact on hydrology, soil temperature, structure, composition, ecological processes, or other aspects of ecological integrity of this ecosystem.	1
Moderate Vulnerability (=High Adaptive Capacity)	Change in snowpack has low impact on hydrology, soil temperature, structure, composition, ecological processes, or other aspects of ecological integrity of this ecosystem.	2
High Vulnerability (=Moderate Adaptive Capacity)	Change in snowpack has moderate impact on hydrology, soil temperature, structure, composition, ecological processes, or other aspects of ecological integrity of this ecosystem.	3
Very High Vulnerability (=Low Adaptive Capacity)	Change in snowpack has significant impact on hydrology, soil temperature, structure, composition, ecological processes, or other aspects of ecological integrity of this ecosystem. Persistence of this ecosystem is strongly dependent on snowpack.	4

AC4. Adaptive Capacity to Summer Maximum Temperature

Definition: An ecosystem's ability to adapt to increases in maximum summer temperatures (June – August) due to climate change.

Background: Increases in summer maximum temperature can have significant effects on wetland ecosystems. Increases in temperature can cause decreases in available water, even if precipitation amounts and patterns remain unchanged (Franklin et al., 1991). Projected increases in temperature will likely increase evapotranspiration enough that even with modeled increases in total annual precipitation, the Pacific Northwest will see an overall net loss of water due to climate change (Halofsky et al., 2022). Increased evapotranspiration due to higher temperatures, coupled with decreases summer and fall precipitation, is likely to lead to a greater water deficit in Washington (Abatzoglou et al., 2014). The baseline temperature regime is less variable on the west side of the

Cascades relative to the east side (Lawler & Mathias, 2007) and ecosystems that occur primarily west of the Cascades may have less adaptive capacity to increases in summer maximum temperature because of this relatively stability (Girvetz et al., 2009).

Summer maximum temperature encompasses extreme heat waves similar to the heat dome that the Pacific Northwest experienced in late June and early July of 2021 (Heeter et al., 2023; Salathé et al., 2023). The 2021 heat dome would not have been likely without anthropogenic climate change and climate change will increase the possibility of similar events in the future (Heeter et al., 2023). Extreme heat is correlated with increased drought, wildfire risk, and increases in area burned (Halofsky et al., 2022).

Increases in summer maximum temperatures can change fire patterns. In the early Holocene, hotter, drier summers were associated with increased fire frequency and range expansion of fire-adapted tree species (Halofsky et al., 2020). While fire is less likely to have direct effects on wetland ecosystems, it can have indirect effects on nutrient inputs and hydrology (e.g., tree loss can reduce evapotranspiration and raise water tables) (e.g., Lavoie & Pellerin, 2007) and some wetlands with relatively ephemeral hydrological regimes may readily burn.

Even small changes in temperature can result in noticeable changes in flood magnitude (Lawler & Mathias, 2007). Evidence from the Mississippi River Basin found that increases in temperature by 1 – 2 ºC accompanied by increases in precipitation by 10 – 20% caused significant increases in flood magnitude and frequency (Poff et al., 2002). Shifts in flood frequency can alter community and ecosystem structure and type (Poff et al., 2002).

Temperature increases can also affect soil biogeochemistry, decomposition, and water availability (Brown et al., 2015). Drying and warming can disrupt carbon sink dynamics in mountain wetlands (Daugherty et al., 2019), with increases in soil temperature increasing carbon loss from ecosystems (Fellman et al., 2017). Warmer temperatures can increase microbial activity in the soil (Perry et al., 2012; Renou-Wilson & Wilson, 2018). This can lead to increases in decomposition rates (Renou-Wilson & Wilson, 2018) and other changes in soil chemistry, nutrient composition, and litter abundance, all of which can change plant productivity, and composition of vegetation communities and their symbionts (Perry et al., 2012).

All of these effects of increases in maximum summer temperature could result in changes in ecosystem structure or type. Higher temperatures are also related to earlier phenology and range shifts northward or to higher elevations, including in studies done in Washington State (e.g., Theobald et al., 2017). Extremely high temperatures can also inhibit photosynthesis and cause photorespiration (Lindner et al., 2010). Some studies also found that increased temperatures could result in decreases in *Sphagnum* and increases in vascular plants in peatlands (Mauquoy & Yeloff, 2008; Hedwall et al., 2017). Warmer summer temperatures are also likely to increase or shift insect outbreaks (Littell et al., 2010; Howe et al., 2025). In the Pacific Northwest, some insect herbivores may shift in range to track their preferred climate envelope, with some regions experiencing an increase in outbreaks and other regions experiencing a decrease in outbreaks as thermal tolerances of pest species are also exceeded (Howe et al., 2025).

Assessment Protocol: Using professional expertise and relevant literature review, choose the best option from **Table 11**. This metric addresses how well an ecosystem may adapt to increases in maximum summer temperatures. Though increases in temperature can affect drought and snowpack, drought is addressed in Adaptive Capacity to Summer Drought (AC5), and changes in snowpack are addressed in Adaptive Capacity to Snowpack Change (AC3).

Consider potential abiotic processes impacted by increases in temperature. Are these impacts expected to shift ecological processes, community composition, or ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of increased temperature?

Table 11. Adaptive Capacity to Summer Maximum Temperature (AC4) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Increased summer maximum temperature has little to no impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • The ecosystem occurs in places that receive large variation in daily or seasonal temperatures.	1
Moderate Vulnerability (=High Adaptive Capacity)	Increased summer maximum temperature has low impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	2
High Vulnerability (=Moderate Adaptive Capacity)	Increased summer maximum temperature has moderate impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	3
Very High Vulnerability (=Low Adaptive Capacity)	Increased summer maximum temperature has significant impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • The ecosystem occurs in places that don't receive large variation in daily or seasonal temperatures.	4

AC5. Adaptive Capacity to Precipitation Drought in Summer

Definition: An ecosystem's adaptive capacity to decreases in precipitation during the months of June to August.

Background: Though models suggest an increase in total annual precipitation in Washington, they also suggest that precipitation amounts will decrease in the summer (Lawler & Mathias, 2007; Mote & Salathé, 2010; Mauger et al., 2015). This sort of shift in precipitation patterns could have significant effects on wetland ecosystems, even if the overall amount of precipitation remains unchanged. Though historically less than 10% of Washinton's annual precipitation arrives during the summer, summer droughts can still affect available water in wetland ecosystems (Mauger et al., 2015).

Evidence suggests more frequent droughts will occur worldwide with climate change (Seavy et al., 2009). Decreases in summer precipitation combined with increases in evapotranspiration and water demand could affect wetland hydrology (Mote & Salathé, 2010). Drier conditions will lower water tables and dry wetlands earlier in the season (Poff et al., 2002). Lowered water tables can also disrupt wetland connectivity (Marcotte et al., 2024). Reductions in precipitation can cause permanent wetlands to become ephemeral and ephemeral wetlands to disappear (Halabisky, 2017; Halofsky et al., 2022). Wetlands that are fed by surface and ground water will likely be less sensitive to drought than wetlands fed by precipitation only (Lawler & Mathias, 2007).

Decreases in available water and disruptions to hydrology will also affect biotic communities. Dry soils can reduce microbial activity, and drought can skew the sex ratios in some dioecious plant species (Perry et al., 2012). Drought can also change vegetation communities, for example favoring vascular plants and decreasing *Sphagnum* in peatlands (Hedwall et al., 2017; Barel et al., 2021). Trees may encroach on drying wetlands, potentially further lowering water tables via evapotranspiration (Bach & Conca, 2004; Hedwall et al., 2017). Changes in timing of ephemeral pond and wetland drying can also have significant trophic effects (e.g., on breeding water birds) (McKenna et al., 2021), as well as disrupting vegetation communities.

Increases in the chance of drought can also increase chances of extreme heat (Salathé et al., 2023). Less soil moisture can result in less evaporative cooling from evapotranspiration, leading to increased temperatures in the summer (Salathé et al., 2023). Drought is one of several factors that can disrupt carbon sink dynamics in mountain wetlands (Daugherty et al., 2019). Summer drought is also closely related to developing wildfire conditions in the Pacific Northwest, and will interact with early snowmelt to increase the likelihood of wildfire ignition (Halofsky et al., 2022). While wetlands are often fire refugia, there may still be indirect effects of fire (e.g., influx of nutrients into wetlands, changes to water tables) and some wetlands with relatively ephemeral hydrological regimes may readily burn (Markle et al., 2022; Jones et al., 2024; Li et al., 2024).

Assessment protocol: This metric addresses how well an ecosystem may adapt to a decrease in precipitation in summer, even if overall total annual precipitation remains unchanged. Using professional expertise and relevant literature review, choose the best option from Table 12. Changes in amount, intensity, and type of precipitation are evaluated in Adaptive Capacity to Total Annual Precipitation (AC1), Adaptive Capacity to Extreme Precipitation Events (AC2), and Snowpack Change (AC3). Changes in temperature are evaluated in Adaptive Capacity to Summer Maximum Temperature (AC4).

Consider potential abiotic processes impacted by decreases in summer precipitation. Do you expect those impacts to shift ecological processes, community composition, or ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of decreased precipitation? For example, ecosystems that depend on precipitation alone for their water source may be more vulnerable to changes in precipitation patterns, particularly if that ecosystem also requires a stable water table. Ecosystems that are adapted to extended dry periods may have greater adaptive capacity to changes in precipitation patterns.

Table 12. Adaptive Capacity to Precipitation Drought in Summer (AC5) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Summer drought has little to no impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • The ecosystem has a stable source of water that is relatively unaffected by summer droughts. • The ecosystem is already well-adapted to drought and is likely to adapt to increased drought likelihood.	1
Moderate Vulnerability (=High Adaptive Capacity)	Summer drought has low impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	2
High Vulnerability (=Moderate Adaptive Capacity)	Summer drought has moderate impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem.	3
Very High Vulnerability (=Low Adaptive Capacity)	Summer drought has significant impact on the structure, composition, hydrology, ecological processes, or other aspects of ecological integrity of this ecosystem. Examples include: • More frequent summer droughts are likely to change hydrological conditions (e.g., shift perennial wetlands to ephemeral wetlands). • More frequent summer droughts are likely to change ecological processes (e.g., increasing decay rates).	4

AC6. Adaptive Capacity to Sea level Rise

Definition: An ecosystem's ability to adapt to rises in sea level.

Background: The Intergovernmental Panel on Climate Change (IPCC) considers coastal regions among the most vulnerable to climate change (Schneider et al., 2007). Salt water intrusion and inundation due to increasing sea levels could have direct impacts on coastal salt marshes and freshwater tidal wetlands (Mote & Salathé, 2010). Several factors are likely to affect a ecosystem's ability to adapt to sea level rise, including coastal uplift or settling (Mauger et al., 2015), sediment inputs (including from freshwater systems like rivers) (Poff et al., 2002; Day et al., 2008; Defne et al., 2020), and natural and anthropogenic barriers to ecosystem migration (Day et al., 2008).

Rises in sea level usually result in migration of tidal wetlands (Brinson, 1993). Historically, coastal marshes have been able to form at the same rate as changes in sea level, but they may struggle to keep up with more rapid rates of sea level rise from anthropogenic climate change (Day et al., 2008). A study in California suggests sea level rise on the Pacific Coast of North America has been slower than other places due to continental uplift (Parker & Boyer, 2019). However, topography may limit the ability for Pacific Coast wetlands to move inland as sea level rises (Parker & Boyer, 2019).

Sea level rise is expected to accelerate coastal erosion (Day et al., 2008). Tidal ecosystems are sensitive to changes in sediment balance and accumulation (Brinson, 1993). The ability to retain sediments is important to resilience of tidal marshes (Defne et al., 2020) and coastal wetlands require continued input of sediment to persist during sea level rise (Poff et al., 2002). Plant productivity is also important for a coastal wetland's ability to keep up with sea level rise (Parker & Boyer, 2019).

Assessment protocol: Using professional expertise and relevant literature review, choose the best option from Table 13. This metric addresses how well an ecosystem may adapt or move in response to sea level rise. If an ecosystem was rated NA for exposure to Sea Level Rise (EX6), it should also be rated NA for this metric.

When assessing an ecosystem's adaptive capacity to sea level rise, it is useful to consider what factors exist that might restrict a coastal ecosystem from shifting inland as sea levels rise (Day et al., 2008). Consider only natural barriers when evaluating adaptive capacity, anthropogenic barriers are evaluated in Threats. Salinity tolerance is also important to consider (Defne et al., 2020). Do you expect the impacts of sea level rise to shift ecological processes, community composition, or ecosystem type? What mechanisms or buffers are present within the ecosystem that could mitigate the effects of rising sea levels?

Table 13. Adaptive Capacity to Sea Level Rise (AC6) Metric Ratings.

Rating	Description	Points
Low Vulnerability	A negligible number of occurrences of a freshwater ecosystem are expected to be affected by saltwater intrusions OR Ecosystem is adapted to salty (hyper- to euhaline) or brackish (mixohaline) conditions and generally has space and sufficient outside sediment inputs to allow the ecosystem to track sea level rise.	1
Moderate Vulnerability	A few occurrences of a freshwater ecosystem are expected to be affected by significant saltwater intrusions. OR Only a few occurrences of a salty/brackish ecosystem have significant natural barriers to upslope movement.	2
High Vulnerability	Many occurrences of a freshwater ecosystem are expected to be affected by significant saltwater intrusions. OR Only a few occurrences of a salty/brackish ecosystem have significant natural barriers to upslope movement.	3

Very High Vulnerability	Most occurrences of a freshwater ecosystem are expected to be affected by significant saltwater intrusions. OR Most occurrences of a salty/brackish ecosystem have significant natural barriers to upslope movement.	4

AC7. Diversity of Biophysical Setting and Variability of Supporting Hydrological Conditions

Definition: An estimation of an ecosystem's adaptive capacity based on the diversity of biophysical settings and hydrological conditions in which it occurs. Biophysical settings are defined by hydrogeomorphological (HGM) class (Brinson, 1993). Hydrological conditions are based on the hydrological regime (Table 14) and water source (Table 15) (Cowardin et al., 1979; Rocchio et al., 2024).

Table 14. Hydrological regime definitions adapted from Level 2 Wetland EIA protocols (Rocchio et al., 2024) and Cowardin et al. (1979). Artificial wetlands are not included.

Hydrological Regime	Definition
Nontidal	
Saturated	Substrate is saturated to the surface for nearly the entire year, but surface water is seldom present, or if present, just a few inches above the soil surface in low spots.
Seasonally saturated	Substrate is saturated to the surface through late spring/early summer, but thereafter tends to dry out.
Permanently flooded	Water covers the surface throughout the year in all years.
Intermittently exposed	Surface water is present throughout the year except in years of extreme drought.
Semipermanently flooded	Water covers the surface throughout the growing season in most years. When surface water is absent the water table is usually at or very near the surface.
Seasonally flooded	Surface water is present for extended periods, especially early in the growing season, but absent by the end of the season in most years. When surface water is absent, the water table often remains near the surface.
Temporarily flooded	Surface water is present for brief periods during the growing season, but the water table usually lies well below the surface for most of the season. Plants that grow in both uplands and wetlands are characteristic.
Intermittently flooded	The substrate is usually exposed, but surface water is present for variable periods without detectable seasonal periodicity. Weeks, months, or even years may intervene between periods of inundation. Dominant plant communities may change as soil moisture conditions change. Some areas aren't considered wetlands under USFWS definitions.
Saltwater Tidal	
Subtidal	Substrate is permanently flooded with tidal water
Irregularly exposed	Substrate is exposed by low tides less often than daily
Regularly flooded	Tidal water alternately floods and exposes the land surface at least once daily.
Irregularly flooded	Tidal water floods the land surface less often than daily

Freshwater Tidal	
Temporarily flooded-tidal	Same definition as above but for tidal sites
Seasonally flooded-tidal	Same definition as above but for tidal sites
Semipermanently flooded-tidal	Same definition as above but for tidal sites
Permanently flooded-tidal	Same definition as above but for tidal sites

Table 15. Water sources adapted from Level 2 Wetland EIA protocols (Rocchio et al., 2024) and Cowardin et al. (1979). Artificial water sources are not included.

Overbank flooding	Precipitation
Alluvial aquifer	Snowmelt
Groundwater discharge	Natural surface flow

Background: Understanding a wetland ecosystem's supporting hydrological conditions is important for determining its adaptive capacity to climate change (Pitchford et al., 2012). Hydrology interacts with regional climate to form wetland ecosystems (Brinson, 1993; Lee et al., 2015). Biophysical setting, hydrological regime, and water source interact with climate to determine wetland type: e.g., a depressional wetland fed only by rainwater in a dry climate will be ephemeral, and in a moist climate may develop into peatland (Brinson, 1993). Ecosystems that occur over a greater variety of biophysical settings, hydrological regimes, and water sources may have more adaptive capacity to changes in climate exposure.

Hydrological regime describes the variability and position of the water table (Cowardin et al., 1979). Hydrological regime can determine composition and structure of vegetation communities (and the larger biotic community) as well as abiotic conditions like erosion and substrate composition (Cowardin et al., 1979). Variability within hydrological regimes (e.g., daily variation in tides, seasonal variation in water tables) is important for structuring ecosystems (Brinson, 1993). Both the energy and source of water inputs can affect vegetation community and structure (Brinson, 1993). Vegetation communities can be sensitive to the timing of floods, changes in timing could affect survival, particularly if floods occur during the growing season (Brinson, 1993). Increased variability in hydrological regime, particularly in ecosystems that are adapted to stable conditions, can lead to increased decomposition and carbon loss (Gignac & Vitt, 1994; Kolka et al., 2018), and potentially shifts to other ecosystem types.

Water source influences permanence of wetlands and stability of water table, e.g., wetlands fed by precipitation only may have more fluctuation in water table levels than wetlands fed by groundwater (Cowardin et al., 1979; Brinson, 1993). Water source (e.g., overbank flooding, surface flow, groundwater discharge) and hydroperiod (the daily, seasonal, annual, or greater scales that water sources fluctuate on) are all important in determining wetland ecosystem types (Brinson, 1993; Pitchford et al., 2012; Halabisky et al., 2017). Wetlands that are dependent on precipitation will be the most vulnerable to climate change (Poff et al., 2002; Lawler & Mathias, 2007; Pitchford et al., 2012), though interactions between temperature and precipitation will affect all wetlands (Pitchford et al., 2012). Groundwater fed wetlands are more likely to persist through seasonal droughts, and will likely be the most resilient to climate change (Poff et al., 2002;

Pitchford et al., 2012). Groundwater sources can also have stabilizing influences on water temperature in wetlands (Dick et al., 2015), and are particularly important for maintaining wetlands in arid ecosystems (Seavy et al., 2009).

Assessment Protocol: Using professional expertise and relevant literature review, choose the best options from

Table 16. Consider the prevalence of particular HGM classes for the ecosystem—some HGM classes may be merely incidental (and safely ignored for the purposes of rating this metric). Consider if hydrological conditions are fairly stable (e.g., bogs and fens), experience annual variation (e.g., marshes), interannual variation (e.g., vernal pools), or some other variation (e.g. tidal wetlands). What is the water source (e.g., ground water, surface water, precipitation)?

Consider what biotic processes may be impacted by changes in hydrology. Do you expect those impacts to shift ecological processes, community composition, or ecosystem type? What mechanism or buffers are present within the ecosystem that could mitigate the effects of decreased precipitation?

HGM class, hydrological regime, and water source will interact to determine an ecosystem's vulnerability. For example, depressional wetlands that depend on precipitation alone for their water source may be more vulnerable to changes in hydrological conditions, particularly if that ecosystem also requires a stable water table. Ecosystems that are adapted to extended dry periods, or that recharge via groundwater may have greater adaptive capacity to climate change.

Table 16. Diversity of Biophysical Settings and Variability of Supporting Hydrological Conditions (AC7) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	Ecosystem occurs in diverse biophysical and hydrological settings, indicating that it may have very high adaptive capacity to climate change. • Ecosystem occurs in four or more HGM classes. • The ecosystem occurs across four or more hydrological regimes. • Ecosystem has more than one water source. • Ecosystem is adapted to variable hydrology	1
Moderate Vulnerability (=High Adaptive Capacity)	The ecosystem occurs in a variety of biophysical and hydrological settings, but the settings it occurs in are still somewhat limited. For example, an ecosystem has moderate vulnerability if it occurs in three HGM classes • The ecosystem usually occurs in 3 HGM classes • The ecosystem occurs in 3 hydrological regimes.	2
High Vulnerability (=Moderate Adaptive Capacity)	The ecosystem is limited to a few biophysical and hydrological settings. • The ecosystem usually occurs in only two HGM classes.	3

	• The ecosystem occurs in only 2 hydrological regimes.	
Very High Vulnerability (=Low Adaptive Capacity)	The ecosystem is limited to a specific biophysical and hydrological setting. • The ecosystem occurs in only one HGM class (e.g., vernal pools). • The ecosystem is dependent on stable hydrological processes (e.g., peatlands). • The ecosystem occurs only in one hydrological setting.	4

Distribution and Range

This section evaluates how an ecosystem's distribution and range affect its ability to respond to climate change. Distribution and range will affect how vulnerable an ecosystem is to stochastic events. An ecosystem with broader distribution will be more resilient to events that could damage occurrences. Location within its range can determine how much exposure and adaptive capacity an ecosystem has, with occurrences in drier or warmer parts of the range having greater vulnerability. In Washington this might be low elevation, southern, or eastern extents of the range.

AC8. Current Extent

Definition: Depending on data availability, this is either a) the range extent AND the total area occupied by the ecosystem, b) the range extent only, or c) the number of ecoregions in which the ecosystem occurs in Washington.

Background: Ecosystems with greater extent likely have greater adaptive capacity to climate change. Larger ranges spread stochastic risks over a greater area (Master et al., 2012). Considering the area and spatial pattern of occupancy within that range is also important (Faber-Langendoen et al., 2012; Lyons et al., 2024). Larger areas of occupancy increase the likelihood of redundancy in ecosystem occurrences (Master et al., 2012). Both of these factors reduce the overall risk to an ecosystem and increase its resiliency to changes in disturbance patterns, hydrology, or other climate change impacts.

Assessment Protocol: This metric has three variants, depending on the quality and completeness of your data. Use the following procedure to select the appropriate variant:

1. Do you have reasonably complete, ground-truthed mapping—often only the case for extremely rare types—or a relatively accurate model of ecosystem locations?

   Yes = Use the 'Range Extent + Area Occupied' variant (AC8 v1)

   No = GO TO 2

2. Do you lack complete mapping, but have plot data or other spatial data that give a generalized sense of the ecosystem's range?

   Yes = Use the 'Range Extent Only' variant (AC8 v2)

No = GO TO 3

3. Use the 'Ecoregional Diversity' variant (AC8 v3)

RANGE EXTENT + AREA OCCUPIED (AC8 v1): This variant requires calculation of both the range extent and area occupied by the ecosystem.

- Range extent is the "spatial spread of areas currently occupied by a species or ecosystem" and can be measured using a "minimum convex hull" (Master et al., 2012). One simple way to complete this measurement is by importing spatial data into GeoCAT (https://geocat.iucnredlist.org/) (Bachman et al., 2011).

- Area occupied (or area of occupancy) is the actual land surface covered by an ecosystem within its range. This can be tabulated directly from your mapping or model data. GeoCAT can also calculate area of occupancy if appropriate data is uploaded.

Once you have calculated both range extent and area occupied, select a rating from Table 17. Range extent and area occupied bins are adapted from Master et al. (2012). If range extent matches one rating, but area occupied matches another, a range rating may be selected (e.g. Low-Moderate).

RANGE EXTENT ONLY (AC8 v2): This variant is used when knowledge of an ecosystem's distribution is incomplete or imprecise, but there are at least some spatial data sets available. Using the data at hand, calculate the range extent (as described above) and select a rating from Table 17. This is the primary variant used by WNHP for evaluating USNVC groups and alliances in Washington. Potential data sets include the WNHP Data Explorer (https://dnr.wa.gov/natural-heritage-program/wnhp-data-explorer), available plot data, relevant literature, and professional expertise.

ECOREGIONAL DIVERSITY (AC8 v3): This variant is only used when distribution data is lacking or extremely suspect. Based on the ecoregions that the ecosystem is known or suspected to occur in, select a rating from Table 17.

Table 17. Current Extent (AC8) Metric Ratings.

Rating	v1 Range Extent + Area Occupied	v2 Range Extent Only	v3 Ecoregional Diversity	Points
Low Vulnerability (=Very High Adaptive Capacity)	Range is >20,000 km^2 Area occupied is > 100 km^2	Range is > 20,000 km^2	Occurs in >3 ecoregions	1
Moderate Vulnerability (=High Adaptive Capacity)	Range is 5,000-20,000 km^2 Area occupied is 21-100 km^2	Range is 5,000-20,000 km^2	Occurs in 3 ecoregions	2

High Vulnerability (=Moderate Adaptive Capacity)	Range is 250-1,000 km^2 Area occupied is 5-20 km^2	Range is 250-1,000 km^2	Occurs in 2 ecoregions	3
Very High Vulnerability (=Low Adaptive Capacity)	Range is <250 km^2 Area occupied is <5 km^2	Range is <250 km^2	Occurs in 1 ecoregion	4

AC9. Location within Geographic Range

Definition: The position of an ecosystem in Washington relative to its global range.

Background: The location of an ecosystem relative to its global range can impact its adaptive capacity. Ecosystem occurrences at the edge of their distribution are expected to be more sensitive to changes in climate, as these occurrences already exist at the limit of their abiotic and climate tolerances (Lawler & Mathias, 2007).

In the northern hemisphere, gene flow from southern regions may make ecosystems and species at the northern edge of their range more resilient to climate change then those at the southern edge of their range (Lindner et al., 2010), where species may be less likely to have a pre-adapted gene pool to bolster their adaptive capacity (Lindner et al., 2010). Ecosystems at the edge of ecoregions and biomes are also more likely to experience shifts in community composition due to climate change (Lawler & Mathias, 2007). Note, however, that occurrences at the southern edge of an ecosystem's range extent may not always be more vulnerable to climate change than those at their northern edge (e.g., Sheth & Angert, 2016).

Elevation may also affect an ecosystem's adaptive capacity to climate change, with ecosystems at lower elevations having greater adaptive capacity (Mamantov et al., 2021). Low-elevation ecosystems may be able to shift their range to higher elevations, whereas those at higher elevations will eventually run out of physical space.

A recent meta-analysis of climate-induced elevation shifts in species found that most studied species had shifted upwards in elevation (Mamantov et al., 2021). The rate and magnitude of these movements may be influenced by breadth of thermal tolerances (species with broader thermal tolerances may be better able to adapt in place), or reproductive capabilities (species with greater reproductive effort may be better able to shift their range) (Mamantov et al., 2021).

Elevational and latitudinal range shifts are expected to be complicated by biotic interactions (e.g., competition, herbivory, mutualisms) (Ettinger & Hille Ris Lambers, 2013; Hille Ris Lambers et al., 2013), individual species traits (Mamantov et al., 2021) and/or abiotic conditions (Mamantov et al., 2021).

Assessment Protocol: Use USNVC group and alliance descriptions (https://explorer.natureserve.org/), the USNVC group map (NatureServe, 2025), WNHP Data Explorer (WNHP, 2025), available plot data, relevant literature, and professional expertise to evaluate the relative placement of the ecosystem within Washington relative its global range and choose the best option from Table 18. This metric has only three rating options.

When assessing this metric, it may also be useful to consider elevation gradients, which can resemble the effects of latitude on the ecosystem (Faber-Langendoen et al., 2012). High elevation communities may also experience higher vulnerability due to their geographic location. Occurrence only at high elevations likely also indicates an ecosystem is at the southern extent of its range.

Table 18. Location within Geographic Range (AC9) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	The ecosystem's distribution in WA is in the northern half of its global range.	1
Moderate-High Vulnerability (= High-Moderate Adaptive Capacity)	The ecosystem's distribution in WA is in the southern 25-50% of its global range. Occurrences may be smaller or significantly fewer in Washington than they are further north.	2.5
Very High Vulnerability (=Low Adaptive Capacity)	The ecosystem's distribution in WA is in the southern 25% of its global range OR the ecosystem only occurs at high elevations in Washington (typically > 4500 feet).	4

Diversity, Community Structure, and Community Dynamics

This section evaluates how an ecosystem's floristic diversity, community structure, and community dynamics affect its adaptive capacity to climate change. Ecosystems with high diversity or dominated by generalist species are expected to have greater adaptive capacity than systems with low diversity or dominated by specialized species.

AC10. Vulnerability and Redundancy of Key Component Species

Definition: AC10 is divided into two submetrics, Vulnerability of Key Species (AC10.1) and Redundancy of Key Component Species (AC10.2). AC10.1 assesses how key component species may respond to climate change, and how that affects the adaptive capacity of an ecosystem as a whole. AC10.2 assesses whether key component species co-occur with other species that fill similar niches or support similar ecosystem processes, and how that redundancy (or lack thereof) contributes to an ecosystem's adaptive capacity as a whole.

Key component species consist of dominant, diagnostic, or other species known to be critical to ecosystem processes.

Background: If key component species are vulnerable to climate change, we expect that the entire ecosystem will have increased vulnerability due to the potential loss of important ecological processes or species interactions. Individual species' adaptive capacity to climate change will contribute to (or limit) an ecosystem's adaptive capacity. Key component species can affect an ecosystem's adaptive capacity through their individual vulnerability to climate change or through their irreplaceability within a community.

Climate change is expected to lead to changes in biodiversity and vegetation community structure and composition (e.g., Theobald et al., 2007; García Criado et al., 2025). Individual species are expected to have different responses to climate change and vegetation communities are not expected to shift as intact units (Franklin et al., 1991; García Criado et al., 2025). Long-lived species such as trees and alpine plant species are likely more vulnerable to climate change because their lifespans and dispersal mechanisms make them less able to keep up with changes in climate (Walker & Pellatt, 2008; Lindner et al., 2010; Thorne et al., 2016). Specialist species may also be more vulnerable to climate change because specialization can reduce genetic variation within a population (Williams et al., 2008; Swanston et al., 2011; Sheth & Angert, 2014). Vulnerability of specialist species should be considered on a case-by-case basis, since not all specialized or narrowly distributed species necessarily have limited genetic variation or adaptive capacity (Sheth & Angert, 2014). Species at the edges of their ranges—particularly the southern edge where pre-adapted gene flow is unlikely—may have more difficulty adapting to climate change than species at the center of their range (Lindner et al., 2010). However, not all species will exhibit this pattern (e.g., Sheth & Angert, 2016).

Community composition and redundancy is important for maintaining and structuring ecological processes, and changes in biodiversity or composition could change ecological processes within a wetland (Lindner et al., 2010; Kominoski et al., 2013). Resilience of a vegetation community relies in part on that community's diversity (both richness and evenness) and in part on the redundancy of important contributors to ecological processes (Swanston et al., 2011; Kominoski et al., 2013; Comer et al., 2019). Redundancy is having multiple species that support key ecological structure (e.g., multiple shrub species codominate a riparian shrubland) or processes (e.g., more than one nitrogen-fixing species occurs in a community) (Swanston et al., 2011; Kominoski et al., 2013). Greater species diversity increases the likelihood that important interactions can be rewired following disturbance or change (Marjakangas et al., 2025). A number of processes and relationships may be disrupted by climate change, including pollinator or soil biota mutualisms (Perry et al., 2012; Forrest, 2015; Theobald et al., 2017), plant competition (García Criado et al., 2025), food availability or nutritional value for herbivores (Swanston et al., 2011; Perry et al., 2012), and patterns of disease/insect outbreaks (Kerns et al., 2018; Howe et al., 2025).

Assessment Protocol: First, use USNVC descriptions, available plot data, professional expertise, and relevant literature to determine key component species to assess. Species critical to ecosystem processes should be prioritized for assessment. Wetland ecosystems may host a wide range of rare species, but these should be low priority for assessment unless they are dominant, diagnostic, or otherwise critical to ecosystem processes. This metric is divided into two submetrics.

VULNERABILITY OF KEY SPECIES: Ideally, key species will be evaluated for their climate change vulnerability using NatureServe's CCVI 4.0 protocol (Lyons et al., 2024). However, more rapid assessments may be supplemented in order to efficiently assess a wider suite species. Rapid assessments should focus on evidence of reliance on cold temperatures, stable hydrology, or occurrence at the southern extreme of the species global range. After completing this assessment, choose the best rating from Table 19.

REDUNDANCY OF KEY SPECIES: Using USNVC descriptions, available survey data, relevant literature, and professional expertise to assess redundancy in vegetation structure and ecological processes of the ecosystem, and choose the best option from Table 19. Consider the diversity within individual strata (e.g., more than one species of tree, shrub, herb, or nonvascular). Also consider if there are multiple species critical to important ecological processes (e.g., nitrogen fixers like *Alnus* species, or species like *Sphagnum* that affect water pH). Not all ecosystems are naturally diverse, and only native species should be considered for this metric.

After rating both submetrics, add their points together to determine the overall rating for AC10.

Table 19. Vulnerability of Key Component Species (AC10) Metric Ratings.

Rating	Description	Points
Low Vulnerability (=Very High Adaptive Capacity)	AC10.1) VULNERABILITY OF KEY SPECIES: No key component species are assessed as vulnerable to climate change (e.g., all CCVI or rapid assessments rate as Less Vulnerable) OR One key component species is Moderately Vulnerable (based on CCVI or rapid assessment), but is not the only key component species in the ecosystem.	0.5
	AC10.2) REDUNDANCY OF KEY SPECIES: The ecosystem has five or more redundant species.	0.5
Moderate Vulnerability (=High Adaptive Capacity)	AC10.1) VULNERABILITY OF KEY SPECIES: More than one key component species is Moderately Vulnerable (based on CCVI or rapid assessment) OR The only key component species in the ecosystem is Moderately Vulnerable (based on CCVI or rapid assessment).	1
	AC10.2) REDUNDANCY OF KEY SPECIES: The ecosystem has three to four redundant species.	1
High Vulnerability (=Moderate Adaptive Capacity)	AC10.1) VULNERABILITY OF KEY SPECIES: More than one key component species is Highly Vulnerable (based on CCVI or rapid assessment) OR The only key component species in the ecosystem is Highly Vulnerable (based on CCVI or rapid assessment).	1.5

	AC10.2) REDUNDANCY OF KEY SPECIES: The ecosystem has two to three redundant key component species	1.5
Very High Vulnerability (=Low Adaptive Capacity)	AC10.1) VULNERABILITY OF KEY SPECIES: More than one key component species is Extremely Vulnerable (based on CCVI or rapid assessment) OR The only key component species in the ecosystem is Extremely Vulnerable (based on CCVI or rapid assessment).	2
	AC10.2) REDUNDANCY OF KEY SPECIES: The ecosystem has no or very low redundancy in key component species (zero or one redundant species).	2

2.4.4 Threats (10% of Score)

This section evaluates how anthropogenic stressors affect the ecosystem's ability to adapt to climate change and how climate change may exacerbate existing stressors. It is modeled on the CCVI 4.0 Threat Multipliers section (Lyons et al., 2024) and the Sensitivity section from Comer et. al (2019)'s Habitat Climate Change Vulnerability Index (HCCVI). CCVI 4.0 defines threats as anthropogenic stressors and other non-climate factors that could change how effectively a population or community can respond to climate change (Lyons et al., 2024). HCCVI also evaluates how anthropogenic stressors changed ecosystem processes and how those changes interacted with climate change (Comer et al., 2019). Comer et al. (2019) theorized that their patterns of upland vegetation vulnerability in the western United States were potentially driven by anthropogenic stressors.

TH1. Current Ecological Integrity of Extant Occurrences

Definition: The current ecological integrity of known occurrences of an ecosystem across Washington.

Background: Ecological Integrity Assessments (EIA) produce an estimate of ecosystem health that integrates landscape context and onsite condition relative to a reference site operating with minimal human stressors (= natural range of variability) (Rocchio et al., 2024). This estimate is summarized in an EIA rank. Size may also be factored in to produce an Element Occurrence (EO) rank, which is a means of prioritizing occurrences based on their overall conservation value. Element occurrences are the area of land where a species or ecosystem are or were present (NatureServe, 2002). Occurrences of an ecosystem with high ecological integrity are within the expected natural range of variability, while those with low ecological integrity are outside of that natural range due to anthropogenic stressors (Rocchio et al., 2024). Ecosystems with greater ecological integrity are likely to have better adaptive capacity to climate change exposure than ecosystems that have reduced ecological integrity (Comer et al., 2019).

Anthropogenic disturbance may come in many forms, including changes in hydrology, conversion to urban development or agriculture, and reduced wetland buffers (Nahlik & Fennessy, 2016).

Drainage is one of the greatest threats to wetlands (Kolka et al., 2018), and reduced connectivity impacts the resilience of species and ecosystems (Seavy et al., 2009). For example, fragmentation of wetlands can increase fire danger, while intact wetlands may function as fire refugia (Kirkland et al., 2023). Research has also found that increases in anthropogenic disturbance correlate with decreases in stored soil carbon in U.S. wetlands (Nahlik & Fennessy, 2016), which aside from increasing atmospheric carbon, also suggests changes in biotic processes that could impact a wetland ecosystem's composition and structure.

Assessment Protocol: If available, use EIA data to select the best option from Table 20. Estimates can come from Level 1 (remotely sensed/modeled), Level 2 (rapid, field-based), and/or Level 3 (intensive, plot-based) EIAs if available. If EIA data are unavailable, another option is to base the assessment on EO ranks of element occurrences (EOs) (WNHP, 2025). An EO rank is generated by integrating EIA rank with the size of the occurrence, but older methods used more subjective, non-EIA methodology. Many EOs have EO ranks derived from this older methodology.

In the absence of EIA data, information may be gleaned from an ecosystem's global or subnational element ranking record (= supporting information for its conservation status rank) (Master et al., 2012), USNVC description, plot records that include stressor information, and professional experience.

Table 20. Current Ecological Integrity of Extant Occurrences (TH1) Metric Ratings.

Rating	Description	Points
Low Vulnerability	>75% of area or EOs have excellent or good ecological integrity (A or B EIA ranks or rounded ranks).	1
Moderate Vulnerability	26 – 75% of area or EOs have excellent or good ecological integrity (A or B EIA ranks or rounded ranks).	2
High Vulnerability	11 – 25% of area or EOs have excellent or good ecological integrity (A or B EIA ranks or rounded ranks).	3
Very High Vulnerability	< 10% of area or EOs have excellent or good ecological integrity (A or B EIA ranks or rounded ranks).	4

TH2. Potential for Climate Change to Exacerbate Existing Stressors

Definition: An assessment of how climate change exposure may exacerbate anthropogenic stressors already impacting an ecosystem. Anthropogenic stressors are human activities or processes that destroy, degrade, or impair biodiversity and natural processes (Rocchio et al., 2024).

Background: Anthropogenic stressors can be exacerbated by climate change. Increases in drought and changes in precipitation patterns may increase the impact of anthropogenic disruptions to wetland hydrology such as draining or development (Swanston et al., 2011; Renou-Wilson & Wilson, 2018). Increases in extreme precipitation may increase pollutant runoff into wetlands adjacent to developed areas (e.g., Rocchio et al., 2025). Drying of wetlands caused by climate change can also increase invasions and/or cover of introduced species (e.g., Kominoski et al., 2013). All of these can affect ecosystem structure, composition, and processes.

Assessment Protocol: Using information regarding existing stressors documented in EIA data, element ranking records (= supporting information for its conservation status rank; Master et al., 2012), literature, and professional expertise, choose the best option from Table 21.

When available, supporting data should come primarily from literature, EIAs, or syntheses of the two. In the absence of such data, information may be gleaned from an ecosystem's global or subnational element ranking record, USNVC description, plot records that include stressor information, and professional experience. When considering anthropogenic stressors for this section, stressors adjacent to ecosystems may also be considered, as long as they may impact the integrity of the ecosystem itself (e.g., neighboring urban development can increase runoff and pollution, or logging neighboring uplands can affect wetland water tables, etc.).

Table 21. Potential for Climate Change to Exacerbate Existing Stressors (TH2) Metric Ratings.

Rating	Description	Points
Low Vulnerability	There are no known interactions between climate change and existing anthropogenic stressors that would result in greater impacts to the composition, structure, hydrology, soils, or ecological processes of this ecosystem.	1
Moderate Vulnerability	The interaction between climate change and existing anthropogenic stressors is likely to result in minor degradation of the composition, structure, hydrology, soils, or ecological processes of this ecosystem.	2
High Vulnerability	The interaction between climate change and existing anthropogenic stressors is likely to result in moderate degradation of the composition, structure, hydrology, soils, or ecological processes of this ecosystem.	3
Very High Vulnerability	The interaction between climate change and existing anthropogenic stressors is likely to result in significant degradation of the composition, structure, hydrology, soils, or ecological processes of this ecosystem.	4

2.4.5 Calculate WetEco CCVA Scores & Ranks

For each USNVC group, WetEco CCVA scores and ranks are calculated based on the three sections in the assessment: Exposure, Adaptive Capacity, and Threats. Variation in the alliances within the group may also be documented.

Individual metrics are all worth a total of four points, with higher scores indicating greater exposure or vulnerability (= lower adaptive capacity) to climate change. Each section is assigned a total score and rank based on the metrics rated for that section. Section scores and ranks are assigned by dividing the total number of points earned by the total number of points possible to earn for that section and multiplying by 100. Any metric rated as NA is excluded from the total possible points.

While individual metrics have equal weights within sections (4 points), the sections themselves are weighted such that Exposure and Adaptive Capacity are each worth 45% of the total WetEco CCVA score, while Threats make up the final 10% (Table 1).

The point breakdown for most metrics is:

- Low = 1 point
- Moderate = 2 points (metrics with only three bins have a combined "moderate-high" option worth 2.5 points)
- High = 3 points (metrics with only three bins have a combined "moderate-high" option worth 2.5 points)
- Very High = 4 points

If a metric is reported as a range (e.g., Moderate – High Exposure), use the average score of the range in calculating total section points. A metric rated Moderate – High Exposure would be scored at 2.5 for calculating overall section scores and ratings.

EX3 (Snowpack) and AC10 (Vulnerability and Redundancy of Key Component Species) are calculated by adding up the scores of its component submetrics. Submetrics are worth two points each:

- 0.5 points = Low Exposure or Low Vulnerability/Very High Adaptive Capacity
- 1 point = Moderate Exposure or Moderate Vulnerability/High Adaptive Capacity
- 1.5 points = High Exposure or High Vulnerability/Moderate Adaptive Capacity
- 2 points = Very High Exposure or Very High Vulnerability/Low Adaptive Capacity

If total points for EX3 or AC10 do not equal a whole number they are reported as a range (e.g., 1.5 is reported as Low – Moderate Exposure). Use your expertise to adjust the rolled-up scores if necessary.

Section Roll-Up
The procedure for assigning a final score and rank to each section is as follows:

1.) Add up the total number of points the ecosystem received in that section.

2.) Add up the total number of points possible for that section. Remember that any metric rated NA does not count towards the point total (e.g., ecosystems that do not have exposure to sea level rise do not have any possible points for sea level rise metrics).

3.) Divide the points assigned by the points possible and multiply by 100 to get the section score. Section ranks are determined by quartile:

- < 25 points = Low
- 25 – 49.9 points = Moderate
- 50 points – 74.9 points = High
- ≥75 points = Very High

WetEco CCVA Score and Rank Roll-Up

WetEco CCVA scores and ranks are determined using a weighted average of the section scores:

Exposure * 0.45 + Adaptive Capacity * 0.45 + Threats *0.1

As with the section ranks, WetEco CCVA ranks are divided by simple quartiles:

- < 25 points = Low Vulnerability
- 25 – 49.9 points = Moderate Vulnerability
- 50 points – 74.9 points = High Vulnerability
- ≥75 points = Very High Vulnerability

See Table 22 for an example of how an ecosystem is scored for the WetEco CCVA.

Table 22. Example summary of Exposure, Adaptive Capacity, and Threat metrics for the North Pacific Open Bog & Acidic Fen Group (G284) in Washington. Roll up scores reflect the percentage of points the group received out of the total number of points possible for each section.

		Score	Rating / Rank
Exposure	EX1. Total Annual Precipitation	1	Low Exposure
	EX2. Extreme Precipitation Magnitude	1	Low Exposure
	EX3. Snowpack[1] *Submetrics* EX3.1 Snow Drought by April 1st EX3.2 Snowpack Change	NA	NA
	EX4. Summer Maximum Temperature	3	High Exposure
	EX5. Precipitation Drought in Summer	2	Moderate Exposure
	EX6. Sea Level Rise	NA	NA
	Exposure Rank	**44**	**Moderate Exposure**
Adaptive Capacity	AC1. Adaptive Capacity to Total Annual Precipitation	3.5	High to Very High Vulnerability
	AC2. Adaptive Capacity to Extreme Precipitation Magnitude	3	High Vulnerability

	AC3. Adaptive Capacity to Snowpack Change[1]	NA	NA
	AC4. Adaptive Capacity to Summer Maximum Temperature	4	High to Very High Vulnerability
	AC5. Adaptive Capacity to Precipitation Drought in Summer	3	High Vulnerability
	AC6. Adaptive Capacity to Sea Level Rise	NA	NA
	AC7. Diversity of Biophysical Settings and Variability of Supporting Hydrological Conditions	3	High Vulnerability
	AC8. Current Areal Extent	1	Low Vulnerability
	AC9. Location within Geographic Range	2	Moderate - High Vulnerability
	AC10. Vulnerability and Redundancy of Key Component Species *Submetrics* AC10.1 Vulnerability of Key Species AC10.2 Redundancy of Key Species	2 1 1	Moderate Vulnerability Moderate Vulnerability Moderate Vulnerability
	Adaptive Capacity Rank	**54**	**High Vulnerability**
Threats	TH1. Current Ecological Integrity of Extant Occurrences	2	Moderate Vulnerability
	TH2. Potential for Climate Change to Exacerbate Existing Stressors	3	High Vulnerability
	Threats Rank	**63**	**High Vulnerability**
Overall Vulnerability		**50**	**High Vulnerability**

[1]Only the North Pacific Montane Acidic Fen Alliance (A4412) occurs in areas directly influenced by snowpack in Washington. This alliance received ratings of Very High Exposure and Very High Vulnerability to EX3 (Snowpack) and AC3 (Adaptive Capacity to Snowpack Change).

3 Results

We tested our protocol development by assessing exposure metrics for all wetland groups in Washington and then completing a full assessment of one USNVC group, the North Pacific Open Bog & Acidic Fen Group (G284).

3.1 Exposure

We assigned exposure ratings and scores to all 26 wetland groups in Washington (Appendix C). For most groups, exposure metrics are simply reported as the range of ratings across the ecoregions and elevation bands in which a group is known to occur in Washington. Exposure assessments for these groups amount to a coarse first-pass and have not received in-depth review. The one exception is the North Pacific Open Bog & Acidic Fen Group, which received a full assessment. This group provides an example of how a more thorough assessment can impact the assignment of exposure metrics. Because wetlands in the North Pacific Open Bog and Acidic Fen Group occur both below and above1800 feet in three ecoregions in Washington, this group was initially rated

NA to Very High Exposure for Snowpack (EX3). However, because this group is far more abundant below 1800 feet—where snowpack is not directly relevant—the final rating was adjusted to simply NA. Similar decisions based on professional expertise and more in-depth analysis of ecosystem distribution would likely improve the accuracy and utility of the ratings for the remaining USNVC wetland groups in the state.

Additionally, no ratings were assigned to component alliances within groups other than North Pacific Open Bog and Acidic Fen. Individual alliances may have different exposure risks than the group as a whole. Exposure metrics for alliances will be reported in future WetEco CCVA assessments for these groups, using the protocols outlined in this document.

All wetland ecosystems in Washington received overall exposure ranks of either moderate or high. The two climate exposure metrics that exhibit the greatest change in Washington are Snowpack (EX3) and Summer Maximum Temperature (EX4). Most wetland ecosystems that received high exposure ranks occur in montane, subalpine, or alpine zones that are directly affected by changing snowpack patterns. In all ecoregions, elevation bands above 1800 feet have very high exposure to Snowpack Change (EX3.2, which predicts changes in the amount of water stored as snow on April 1st). The North Cascades is the only ecoregion in which this elevation band is not expected to have high or very high exposure to Snow Drought by April 1st (EX3.1, likelihood that any year has April 1st snowpack < 75% of average). Some research suggests that snowpack loss will be the primary climate change impact in Washington (Elsner et al., 2010). All ecoregions have moderate to high exposure to increases in Summer Maximum Temperature (EX4).

When interpreting results for Total Annual Precipitation (EX1), note that this metric estimates exposure to modeled <u>decreases</u> in total annual precipitation. The model used in this project predicts <u>increased</u> total annual precipitation in all ecoregions and elevation classes in Washington (Raymond & Rogers, 2022; Stewart et al., 2024). Thus, all groups were rated as having low exposure for this metric, even when the modeled increase in precipitation slightly exceeded variation in baseline conditions.

3.2 North Pacific Open Bog & Acidic Fen Assessment

We chose to assess this group because of the importance of peatlands to the global carbon cycle (Parish et al., 2008) and because WNHP staff have significant professional expertise with this group.

The North Pacific Open Bog & Acidic Fen group is expected to have moderate overall exposure to climate change, primarily from increases in Summer Maximum Temperature (EX4). Most occurrences of this group are at low elevations, so the group as a whole was not rated for changes in snowpack (EX3). That said, the North Pacific Montane Acidic Fen Alliance within this group is predicted to have high exposure to changes in snowpack due to climate change.

This group is estimated to have moderate adaptive capacity to climate change, meaning high vulnerability to changes in climate exposure. Peatland dependence on stable hydrological conditions, positive water balance, and cool temperatures limit the adaptive capacity of these ecosystems. Some uncertainty is introduced by the Vulnerability and Redundancy of Key Component Species (AC10) metric, which we found difficult to rate for this group. None of the identified key component species had pre-existing CCVI assessments, so only rapid CCVIs based on the minimum number of metrics were completed. Information regarding individual species responses to climate change was difficult to find, so rapid assessments relied largely on best professional judgment. Future assessments would benefit from additional time budgeted for full CCVI assessments of key species.

The North Pacific Open Bog and Acidic Fen Group also ranked as having high vulnerability to anthropogenic threats. The majority of element occurrences (EOs) of this group are generally in excellent or good condition (WNHP, 2025). However, other anthropogenic threats unrelated to climate change are common (e.g., development, road building, and resource extraction such as logging or peat mining). Threats are expected to interact with changes in climate change exposure, with the potential to increase the negative effects of changes in exposure. For example, an increase in nearby impervious surfaces due to development could exacerbate the negative effects of runoff from increases in extreme precipitation. Increases in temperature and decreases in precipitation could exacerbate the negative effects of disruptions to local hydrology or encroachment by introduced plant species.

Incorporating exposure, adaptive capacity, and threats, the WetEco CCVA estimates high overall vulnerability to climate change for the North Pacific Open Bog & Acidic Fen Group (Table 22). For the complete assessment, see Appendix A.

4 Discussion

The WetEco CCVA framework represents the first method for estimating climate change vulnerability of mid-scale wetland ecosystem types in Washington State, filling a demonstrated need to inform management, conservation, and regulatory decisions regarding climate resilience. Washington State law mandates that state agencies incorporate climate change adaptation plans in their work (RCW 70A.05.010) and the Washington Wetland Program Plan emphasizes the need to understand how climate change will impact distribution, function, and ecological integrity of Washington wetlands and the ecosystem services they provide (Ecology, 2015). More specifically, the statewide wetland monitoring and assessment strategy identified several important data gaps that impede our understanding of climate change effects: (1) What wetland locations and types are potentially vulnerable to the effects of climate change? (2) How will climate change affect the extent and functions of wetlands? (3) Are there types of wetlands that are more resilient to climate change? (4) What role will wetlands play in community resilience to impacts from climate change? This protocol directly addresses questions 1-3, providing guidance for compilation of critical, technical information for land managers, regulators, and conservationists. It also provides a framework for developing and tracking climate change monitoring strategies.

The Washington State Wetland Mitigation Guidance document (Ecology et al., 2021) notes: "The effects of climate change create challenges and opportunities for compensatory mitigation proposals. The primary challenge for applicants is proposing a location and design that will be sustainable over the long term, in addition to successfully meeting permit requirements." The mitigation guidance goes on to state that proposed mitigation projects need to consider the effects of climate change on critical pieces of mitigation such as water supply, selection of native species to seed/plant, potential influx of invasive species, and long-term management goals. Our project provides a tool for assessing which wetland types are most vulnerable to climate change and thus face the greatest challenges for successful mitigation. In addition, our metric-based approach provides specific information for each wetland type regarding hydrological sensitivity, vulnerable component native plant species, and other ecological characteristics that would be prudent to incorporate into long-term mitigation and management goals.

The Washington Department of Natural Resources Plan for Climate Resilience notes that assessing the vulnerability of DNR-managed conservation lands (including natural areas) is an agency priority (WADNR, 2020). Wetlands and riparian areas are primary features of many of these conservation lands and we need to understand their vulnerability so that management can anticipate climate change effects. The WetEco CCVA represents a tool for assessing that vulnerability. As more assessments are completed, we will have a better idea of which existing natural areas are most vulnerable to climate change and also be able to incorporate this information into prioritization of new natural areas.

4.1 Lessons Learned and Future Directions

The process of creating and testing the WetEco CCVA protocol was iterative, with several lessons learned along the way that will inform future directions for the method.

4.1.1 Baseline Exposure Data

The climate change exposure data set used in this effort summarized change between a baseline period (1980-2009) and modeled future conditions (2070-2099) based on the RCP 8.5 pathway (the "business as usual" carbon emissions model) from the CIMP5 climate models. It did not include the baseline data itself, nor any descriptive statistics (standard deviation, etc.) over the baseline period. This arguably limited our ability to interpret what predicted changes in exposure variables might mean for an ecosystem.

For this project, we used PRISM data to calculate baseline period summaries (including variability) for Total Annual Precipitation (EX1) and Summer Maximum Temperature (EX4). We then used these data to create rating bins for these metrics based on the standard deviation of measurements over the baseline period. Rating bins for the remaining exposure metrics are simply based on quartiles, however, and would be improved in future iterations by factoring in historical variability (as we did for EX1 and EX4). Rating bins created for EX1 and EX4 were notably in line with other ecological evidence. For example, the 'very high' exposure bin for EX4 matched the temperature ranges documented during the 2021 heat dome (Reyes and Kramer 2023).

Refining the remaining exposure metrics to include the baseline exposure data as well as the modeled change in exposure is an important next step. While the current method of scaling the data to a percentage of modeled change and then splitting it into quartile-based ratings is comparable with other climate change vulnerability analyses (e.g., Comer et al., 2019), one critique of climate change vulnerability analyses in general is that the methods of assigning ranks are not always statistically sound (Tonmoy et al., 2014). Exposure data that includes baseline measures and descriptive statistics will enable us to refine our scoring procedures to better capture the ecological effects of climate change, as well as improve repeatability and defensibility of our conclusions.

4.1.2 Professional Expertise

The WetEco CCVA incorporates quantitative data and published literature whenever possible, but many metrics represent qualitative assessments relying heavily on professional expertise. WetEco CCVA assessments are more qualitative than some of the other CCVA methods we reviewed for this protocol (e.g., Comer et al. 2019). Users without a strong working knowledge of regional ecosystems and the component flora will need to consult with experts when completing a WetEco CCVA. While future iterations of this method may find additional quantitative approaches that can be incorporated, the largely qualitative protocol presented provides a structured, repeatable framework for relatively rapid assessments of climate change vulnerability.

4.1.3 CCVI of Key Component Species

We recommend completing full Climate Change Vulnerability Index (CCVI) assessments when rating the Vulnerability and Redundancy of Key Component Species (AC10). However, these assessments can be time-consuming, either from an overabundance of data, or—more frequently—from a paucity of information. We recommend that assessors budget ample time in order to complete CCVI assessments for key plant taxa within each WetEco CCVA.

4.1.4 Additional Assessments

Only 1 of the 26 wetland groups in Washington has been assessed at this time. Applying this protocol to the remaining groups will expand our understanding of the range of climate change vulnerabilities of Washington's diverse wetlands and provide important information to land managers. Additional assessments will also help us continue to refine our methods, recommended data sources, and metric weights, besides providing more concrete examples for inclusion in the metric rating tables.

4.1.5 Online USNVC Classification Tool

WetEco CCVAs use US National Vegetation Classification groups as the standard assessment unit. In order to expand the user base of our assessments, we hope to develop and host an online identification tool that will identify the USNVC type represented by a given wetland based on basic information provided by the user. Users will enter basic information about a given wetland, such as elevation, ecoregion, landscape setting, and dominant species and the tool will auto-generate probable USNVC types represented by the wetland. We anticipate this requiring far less technical skill than traditional vegetation keys, though such keys will be essential for building the online tool and will still be provided on WNHP's website.

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Appendix A. WetEco CCVA: North Pacific Open Bog & Acidic Fen (G284)

See accompanying document for the full WetEco CCVA for the North Pacific Open Bog and Acidic Fen Group.

Appendix B. PRISM Data and Metric Rating Bins for Total Annual Precipitation and Summer Maximum Temperature

We used PRISM data (PRISM Climate Group, 2025) to calculate average baseline (1980 – 2009) exposure and variation for two exposure metrics, Total Annual Precipitation (EX1) (Table B-1) and Summer Maximum Temperature (EX4) (Table B-2). We calculated variability by standard deviation, which we used to create rating bins for these two metrics.

Table B-1. Metric bins for Total Annual Precipitation (EX1) as calculated from PRISM precipitation data for the years 1980 – 2009 (PRISM Climate Group, 2025). When evaluating exposure for Total Annual Precipitation, we only considered decreases in precipitation amounts. Any increase in precipitation amount is considered low exposure for this metric.

Ecoregion x elevation class	Low Exposure (mm)	Low Exposure (%)	Moderate Exposure (mm)	Moderate Exposure (%)	High Exposure (mm)	High Exposure (%)	Very High Exposure (mm)	Very High Exposure (%)	1980 - 2009 Baseline (mm)
Blue Mountains <1800ft	66	16 %	66 - 132	16% - 32%	132 - 197	32% - 48%	>197	>48%	409
Blue Mountains >1800ft	131	15%	131 - 261	15% - 31%	261 - 392	31% - 46%	>392	>46%	847
Canadian Rocky Mountains <1800ft	104	17%	104 - 209	17% - 34%	209 - 313	34% - 51%	>313	>51%	618
Canadian Rocky Mountains >1800ft	127	15 %	127 - 254	15% - 31%	254 - 381	31% - 46%	>381	>46%	826
Columbia Plateau <1800ft	55	21%	55 - 110	21% - 42%	110 - 165	42% - 63%	>165	>63%	260
Columbia Plateau >1800ft	69	19%	69 - 137	19% - 37%	137 - 206	37% - 56%	>206	>56%	369
East Cascades <1800ft	114	22%	114 - 227	22% - 44%	227 - 341	44% - 66%	>341	>66%	518
East Cascades >1800ft	214	18%	214 - 428	18% - 37%	428 - 642	37% - 55%	>642	>55%	1163

Ecoregion x elevation class	Low Exposure (mm)	Low Exposure (%)	Moderate Exposure (mm)	Moderate Exposure (%)	High Exposure (mm)	High Exposure (%)	Very High Exposure (mm)	Very High Exposure (%)	1980 - 2009 Baseline (mm)
North Cascades <1800ft	315	14%	315 - 630	14% - 28%	630 - 945	28% - 41%	>945	>41%	2285
North Cascades >1800ft	394	15%	394 - 788	15% - 29%	788 - 1182	29% - 44%	>1182	>44%	2697
Northwest Coast <1800ft	408	17%	408 - 816	17% - 34%	816 - 1224	34% - 50%	>1224	>50%	2433
Northwest Coast >1800ft	511	17%	511 - 1022	17% - 35%	1022 - 1533	35% - 52%	>1533	>52%	2948
Okanogan <1800ft	80	22%	80 - 159	22% - 43%	159 - 239	43% - 65%	>239	>65%	369
Okanogan >1800ft	102	18%	102 - 204	18% - 35%	204 - 306	35% - 53%	>306	>53%	577
Puget Trough <1800ft	173	15%	173 - 345	15% - 30%	345 - 518	30% - 45%	>518	>45%	1145
Puget Trough >1800ft	225	13%	225 - 450	13% - 27%	450 - 675	27% - 40%	>675	>40%	1673
West Cascades <1800ft	302	16%	302 - 603	16% - 32%	603 - 905	32% - 48%	>905	>48%	1886
West Cascades >1800ft	379	17%	379 - 759	17% - 33%	759 - 1138	33% - 50%	>1138	>50%	2266

Table B-2. Metric bins for Summer Maximum Temperature (EX3) as calculated from PRISM temperature data from June to August for the years 1980 – 2009 (PRISM Climate Group, 2025).

Ecoregion x elevation class	Low Exposure (°F)	Moderate Exposure (°F)	High Exposure (°F)	Very High Exposure (°F)	1980 - 2009 Baseline (°F)
Blue Mountains <1800ft	6	6 - 13	13 - 19	>19	87
Blue Mountains >1800ft	6	6 - 13	13 - 19	>19	85
Canadian Rocky Mountains <1800ft	6	6 - 11	11 - 17	>17	82
Canadian Rocky Mountains >1800ft	6	6 - 11	11 - 17	>17	81
Columbia Plateau <1800ft	5	5 - 10	10 - 15	>15	89
Columbia Plateau >1800ft	6	6 - 11	11 - 17	>17	86

Ecoregion x elevation class	Low Exposure (°F)	Moderate Exposure (°F)	High Exposure (°F)	Very High Exposure (°F)	1980 - 2009 Baseline (°F)
East Cascades <1800ft	5	5 - 10	10 - 16	>16	85
East Cascades >1800ft	5	5 - 10	10 - 16	>16	84
North Cascades <1800ft	5	5 - 11	11 - 16	>16	76
North Cascades >1800ft	5	5 - 10	10 - 16	>16	74
Northwest Coast <1800ft	4	4 - 8	8 - 12	>12	78
Northwest Coast >1800ft	4	4 - 9	9 - 13	>13	75
Okanogan <1800ft	5	5 - 11	11 - 16	>16	87
Okanogan >1800ft	5	5 - 11	11- 16	>16	86
Puget Trough <1800ft	5	5 - 9	9 - 14	>14	79
Puget Trough >1800ft	4	4 - 9	9 - 13	>13	72
West Cascades <1800ft	5	5 - 10	10 - 15	>15	79
West Cascades >1800ft	5	5 - 11	11 - 16	>16	77

Appendix C. Exposure Ratings for USNVC Wetland Groups in Washington State

Exposure metrics were rated for all 26 USNVC native wetland groups in Washington State. Table C-1 reports overall scores as well as the ecoregions and elevation bands in which each group occurs. Individual metrics are reported in the subsequent tables (Table C-2, Table C-3, Table C-4, and Table C-5).

Table C-1. Exposure rank, ecoregional distribution, and elevation bands for all assessed USNVC groups.

Group Code	USNVC Group	Ecoregions	Elevation Band	Final Score	Exposure Rank
G531	Arid West Interior Freshwater Marsh & Wet Meadow	Okanogan, Canadian Rockies, Columbia Plateau	Lowland, Montane-Subalpine	37.5 - 52.5	Moderate - High Exposure
G796	Central Rocky Mountain Lowland & Foothill Riparian Forest	East Cascades, Okanogan, Blue Mountains, Canadian Rockies, Columbia Plateau	Lowland, Montane-Subalpine	37.5 - 52.5	Moderate - High Exposure
G538	Desert Alkaline-Saline Marsh & Playa	Columbia Plateau	Lowland, Montane-Subalpine	37.5 - 50	Moderate - High Exposure
G537	Desert Alkaline-Saline Wet Scrub	Columbia Plateau	Lowland	37.5	Moderate Exposure
G385	North American Pacific Intertidal Algal Flat	Puget Trough, Northwest Coast	Lowland	55	High Exposure
G285	North Pacific Circumneutral-Alkaline Fen	Puget Trough, Northwest Coast, North Cascades, West Cascades	Lowland, Montane-Subalpine	35 -52.5	Moderate - High Exposure
G610	North Pacific Maritime Wooded Bog & Poor Fen	Puget Trough, Northwest Coast	Lowland	35	Moderate Exposure
G284	North Pacific Open Bog & Acidic Fen	Puget Trough, Northwest Coast, West Cascades, North Cascades	Lowland, Montane-Subalpine	35	Moderate Exposure
G851	North-Central Pacific Lowland Riparian Forest	West Cascades, Puget Trough, Northwest Coast, North Cascades	Lowland, Montane-Subalpine	37.5 - 55	Moderate - High Exposure
G853	North-Central Pacific Maritime Lowland Swamp	West Cascades, Puget Trough, Northwest Coast, North Cascades	Lowland, Montane-Subalpine	37.5 - 55	Moderate - High Exposure
G507	North-Central Pacific Montane Riparian & Seepage Swamp	West Cascades, Northwest Coast, East Cascades, North Cascades	Montane-Subalpine	50 - 52.5	High Exposure
G529	North Pacific-Columbia Plateau Vernal Pool	Puget Trough, Columbia Plateau	Lowland, Montane-Subalpine	35-40	Moderate Exposure

Group Code	USNVC Group	Ecoregions	Elevation Band	Final Score	Exposure Rank
G515	Rocky Mountain Acidic Fen	Canadian Rockies, Okanogan, East Cascades, North Cascades	Montane-Subalpine	50 -52.5	High Exposure
G516	Rocky Mountain Circumneutral-Alkaline Fen	Canadian Rockies, Okanogan, East Cascades, North Cascades, Columbian Plateau	Lowland, Montane-Subalpine	37.5 -52.5	High Exposure
G526	Rocky Mountain-Great Basin Lowland-Foothill Riparian Shrubland	Columbia Plateau	Lowland	37.5	Moderate Exposure
G506	Rocky Mountain-Great Basin Montane Riparian Forest	Blue Mountains, Canadian Rockies, Okanogan, East Cascades, North Cascades, Columbia Plateau	Montane-Subalpine	40 - 52.5	Moderate - High Exposure
G505	Rocky Mountain-Great Basin Swamp	Canadian Rockies, Blue Mountains, Columbia Plateau, Okanogan, East Cascades, North Cascades	Montane-Subalpine	40 - 52.5	Moderate - High Exposure
G525	Temperate Pacific Freshwater Mudflat	Puget Trough, Northwest Coast	Lowland	40	Moderate Exposure
G499	Temperate Pacific Salt Marsh	Puget Trough, Northwest Coast	Lowland	55	High Exposure
G373	Temperate Pacific Seagrass Bed	Puget Trough, Northwest Coast	Lowland	55	High Exposure
G517	North Pacific Freshwater Wet Meadow & Marsh	West Cascades, Puget Trough, Northwest Coast	Lowland, Montane-Subalpine	35 - 52.5	Moderate - High Exposure
G322	North Pacific Wet Shrubland	Puget Trough, Northwest Coast, North Cascades, West Cascades, East Cascades	Lowland, Montane-Subalpine	35 -52.5	Moderate - High Exposure
G521	Pacific-Rocky Mountain Montane Wet Meadow & Marsh	Northwest Coast, Blue Mountains, West Cascades, Canadian Rockies, Okanogan, East Cascades, North Cascades, Columbia Plateau	Lowland, Montane-Subalpine	37.5 - 52.5	Moderate - High Exposure
G520	Pacific-Rocky Mountain Subalpine-Alpine Snowbed & Wet Meadow	West Cascades, East Cascades, North Cascades	Montane-Subalpine	50 - 52.5	High Exposure
G527	Western Montane-Subalpine Riparian & Seep Shrubland	Blue Mountains, West Cascades, Canadian Rockies, East Cascades, Okanogan, North Cascades, Northwest Coast, Columbia Plateau	Lowland, Montane-Subalpine	37.5 -52.5	Moderate - High Exposure
G544	Western Temperate Freshwater Aquatic Vegetation	Puget Trough, Northwest Coast, Blue Mountains, West Cascades, Canadian	Lowland, Montane-Subalpine	35 - 52.5	Moderate - High Exposure

Group Code	USNVC Group	Ecoregions	Elevation Band	Final Score	Exposure Rank
		Rockies, Okanogan, East Cascades, North Cascades, Columbia Plateau			

Table C-2. Precipitation exposure metrics (Total Annual Precipitation and Extreme Precipitation Magnitude) for assessed USNVC groups. Increases in Total Annual Precipitation (EX1) are considered low exposure (only decreases result in higher exposure ratings in this methodology).

Group Code	USNVC Group	EX1. Total Annual Precipitation			EX2. Extreme Precipitation Magnitude		
		Percent Change	Score	Rating	Percent Change	Score	Rating
G531	Arid West Interior Freshwater Marsh & Wet Meadow	14.77 - 22.93	1	Low Exposure	20.47 - 27.28	1	Low - Moderate Exposure
G796	Central Rocky Mountain Lowland & Foothill Riparian Forest	3.66 - 22.93	1	Low Exposure	11.22 - 25.04	1	Low - Moderate Exposure
G538	Desert Alkaline-Saline Marsh & Playa	18.42 - 22.93	1	Low Exposure	22.06 - 24.22	1	Low Exposure
G537	Desert Alkaline-Saline Wet Scrub	22.93	1	Low Exposure	24.22	1	Low Exposure
G385	North American Pacific Intertidal Algal Flat	6.86 - 10.06	1	Low Exposure	18.24 - 20.40	1	Low Exposure
G285	North Pacific Circumneutral-Alkaline Fen	0.93 - 10.06	1	Low Exposure	14.92 - 23.44	1	Low Exposure
G610	North Pacific Maritime Wooded Bog & Poor Fen	6.86 - 10.06	1	Low Exposure	18.24 - 20.40	1	Low Exposure
G284	North Pacific Open Bog & Acidic Fen	0.93 - 10.06	1	Low Exposure	14.92 - 23.44	1	Low Exposure
G851	North-Central Pacific Lowland Riparian Forest	0.93 - 11.85	1	Low Exposure	14.66 - 23.44	1	Low Exposure
G853	North-Central Pacific Maritime Lowland Swamp	0.93 - 11.85	1	Low Exposure	14.66 - 23.44	1	Low Exposure
G507	North-Central Pacific Montane Riparian & Seepage Swamp	0.93 - 4.81	1	Low Exposure	14.92 - 23.44	1	Low Exposure
G529	North Pacific-Columbia Plateau Vernal Pool	10.06 - 22.93	1	Low Exposure	20.40 - 24.22	1	Low Exposure

Group Code	USNVC Group	EX1. Total Annual Precipitation			EX2. Extreme Precipitation Magnitude		
		Percent Change	Score	Rating	Percent Change	Score	Rating
G515	Rocky Mountain Acidic Fen	4.54 - 14.77	1	Low Exposure	12.56 - 23.92	1	Low Exposure
G516	Rocky Mountain Circumneutral-Alkaline Fen	4.54 - 22.93	1	Low Exposure	12.56 - 24.22	1	Low Exposure
G526	Rocky Mountain-Great Basin Lowland-Foothill Riparian Shrubland	22.93	1	Low Exposure	24.22	1	Low Exposure
G506	Rocky Mountain-Great Basin Montane Riparian Forest	3.66 - 18.42	1	Low Exposure	12.56 - 23.92	1	Low Exposure
G505	Rocky Mountain-Great Basin Swamp	3.66 - 18.42	1	Low Exposure	12.56 - 23.92	1	Low Exposure
G525	Temperate Pacific Freshwater Mudflat	6.86 - 10.06	1	Low Exposure	18.24 - 20.40	1	Low Exposure
G499	Temperate Pacific Salt Marsh	6.86 - 10.06	1	Low Exposure	18.24 - 20.40	1	Low Exposure
G373	Temperate Pacific Seagrass Bed	6.86 - 10.06	1	Low Exposure	18.24 - 20.40	1	Low Exposure
G517	North Pacific Freshwater Wet Meadow & Marsh	3.65 - 10.06	1	Low Exposure	14.66 - 22.00	1	Low Exposure
G322	North Pacific Wet Shrubland	0.93 - 10.06	1	Low Exposure	12.56 - 23.44	1	Low Exposure
G521	Pacific-Rocky Mountain Montane Wet Meadow & Marsh	0.93 - 22.93	1	Low Exposure	12.56 - 24.22	1	Low Exposure
G520	Pacific-Rocky Mountain Subalpine-Alpine Snowbed & Wet Meadow	0.93 - 4.81	1	Low Exposure	12.56 - 23.44	1	Low Exposure
G527	Western Montane-Subalpine Riparian & Seep Shrubland	0.93 - 22.93	1	Low Exposure	12.56 - 24.22	1	Low Exposure
G544	Western Temperate Freshwater Aquatic Vegetation	0.93 - 22.93	1	Low Exposure	12.56 - 29.42	1 - 2	Low - Moderate Exposure

Table C-3. Snowpack exposure metrics for all assessed USNVC groups. Snowpack (EX3) has two submetrics—Snow Drought (EX3.1) and Snowpack Change (EX3.2)—that are added together to produce the overall metric rating.

Group Code	USNVC Group	EX3.1 Snow Drought			EX3.2 Snowpack Change			EX3. Snowpack	
		Likelihoo d of Change	Score	Rating	Percent Change	Score	Rating	Score	Rating
G531	Arid West Interior Freshwater Marsh & Wet Meadow	0.73 - 1.00	NA -1.5	NA - Very High Exposure	-83 - -100	NA - 2	NA - Very High Exposure	NA - 3.5	NA - Very High Exposure
G796	Central Rocky Mountain Lowland & Foothill Riparian Forest	0.56 - 1.00	NA - 2	NA - Very High Exposure	-80 - -100	NA - 2	NA - Very High Exposure	NA - 3.5	NA - Very High Exposure
G538	Desert Alkaline-Saline Marsh & Playa	1.00	NA - 2	NA - Very High Exposure	NA	NA	NA	NA - 2	NA - Moderate Exposure
G537	Desert Alkaline-Saline Wet Scrub	1.00	NA	NA	NA	NA	NA	NA	NA
G385	North American Pacific Intertidal Algal Flat	1.00	NA	NA	-100	NA	NA	NA	NA
G285	North Pacific Circumneutral-Alkaline Fen	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -100	NA - 2	NA - Very High Exposure	NA - 3.5	NA - Very High Exposure
G610	North Pacific Maritime Wooded Bog & Poor Fen	1.00	NA	NA	-100	NA	NA	NA	NA
G284	North Pacific Open Bog & Acidic Fen	0.48 - 1.00	NA	NA	-76 - -100	NA	NA	NA	NA
G851	North-Central Pacific Lowland Riparian Forest	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -100	NA - 2	NA - Very High Exposure	NA - 4	NA - Very High Exposure
G853	North-Central Pacific Maritime Lowland Swamp	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -100	NA - 2	NA - Very High Exposure	NA - 4	NA - Very High Exposure
G507	North-Central Pacific Montane Riparian & Seepage Swamp	0.48 - 0.82	1 - 2	Moderate - Very High Exposure	-76 - -94	2	Very High Exposure	3 - 4	High - Very High Exposure

Group Code	USNVC Group	EX3.1 Snow Drought			EX3.2 Snowpack Change			EX3. Snowpack	
		Likelihood of Change	Score	Rating	Percent Change	Score	Rating	Score	Rating
G529	North Pacific-Columbia Plateau Vernal Pool	1.00	NA	NA	-100	NA	NA	NA - 2	NA - Moderate Exposure
G515	Rocky Mountain Acidic Fen	0.48 - 0.74	1 - 1.5	Moderate - High Exposure	-76 - -90	2	Very High Exposure	3 - 3.5	High - Very High Exposure
G516	Rocky Mountain Circumneutral-Alkaline Fen	0.48 - 1.00	NA - 1.5	NA - High Exposure	-76 - -90	2	Very High Exposure	NA - 3.5	NA- Very High Exposure
G526	Rocky Mountain-Great Basin Lowland-Foothill Riparian Shrubland	1.00	NA	NA	NA	NA	NA	NA	NA
G506	Rocky Mountain-Great Basin Montane Riparian Forest	0.48 - 1.00	1 - 2	Moderate - Very High Exposure	-76 - -98	2	Very High Exposure	2 - 4	Moderate - Very High Exposure
G505	Rocky Mountain-Great Basin Swamp	0.48 - 1.00	1 - 2	Moderate - Very High Exposure	-76 - -98	NA - 2	NA - Very High Exposure	2 - 4	Moderate - Very High Exposure
G525	Temperate Pacific Freshwater Mudflat	1.00	NA	NA	-100	NA	NA	NA	NA
G499	Temperate Pacific Salt Marsh	1.00	NA	NA	-100	NA	NA	NA	NA
G373	Temperate Pacific Seagrass Bed	1.00	NA	NA	-100	NA	NA	NA	NA
G517	North Pacific Freshwater Wet Meadow & Marsh	0.64 - 1.00	NA - 1.5	NA - High Exposure	-89 - -100	NA - 2	NA - Very High Exposure	NA - 3.5	NA - Very High Exposure
G322	North Pacific Wet Shrubland	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -100	NA - 2	NA - Very High Exposure	NA - 4	NA - Very High Exposure
G521	Pacific-Rocky Mountain Montane Wet Meadow & Marsh	0.48 - 1.00	NA - 2	NA - Very High Exposure	-89	2	Very High Exposure	NA - 4	NA - Very High Exposure

Group Code	USNVC Group	EX3.1 Snow Drought			EX3.2 Snowpack Change			EX3. Snowpack	
		Likelihood of Change	Score	Rating	Percent Change	Score	Rating	Score	Rating
G520	Pacific-Rocky Mountain Subalpine-Alpine Snowbed & Wet Meadow	0.48 - 0.82	1 - 2	Moderate - Very High Exposure	-76 - -94	2	Very High Exposure	3 - 4	High - Very High Exposure
G527	Western Montane-Subalpine Riparian & Seep Shrubland	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -98	2	Very High Exposure	NA - 4	NA - Very High Exposure
G544	Western Temperate Freshwater Aquatic Vegetation	0.48 - 1.00	NA - 2	NA - Very High Exposure	-76 - -100	NA - 2	NA - Very High Exposure	NA - 4	NA - Very High Exposure

Table C-4. Seasonal exposure metrics (Summer Maximum Temperature and Precipitation Drought in Summer) for all assessed USNVC groups.

Group Code	USNVC Group	EX4. Summer Maximum Temperature			EX5. Precipitation Drought in Summer		
		Temperature (°F)	Score	Rating	Likelihood of Change	Score	Rating
G531	Arid West Interior Freshwater Marsh & Wet Meadow	11	2 - 3	Moderate - High Exposure	0.25 - 0.33	1 - 2	Low - Moderate Exposure
G796	Central Rocky Mountain Lowland & Foothill Riparian Forest	11	2 - 3	Moderate - High Exposure	0.22 - 0.33	1 - 2	Low - Moderate Exposure
G538	Desert Alkaline-Saline Marsh & Playa	11	2 - 3	Moderate - High Exposure	0.25 - 0.28	1 - 2	Low - Moderate Exposure
G537	Desert Alkaline-Saline Wet Scrub	11	3	High Exposure	0.25	1	Low Exposure
G385	North American Pacific Intertidal Algal Flat	8 - 10	3	High Exposure	0.34 - 0.38	2	Moderate Exposure
G285	North Pacific Circumneutral-Alkaline Fen	8 - 11	2 - 3	Moderate - High Exposure	0.34 - 0.40	2	Moderate Exposure
G610	North Pacific Maritime Wooded Bog & Poor Fen	8 - 10	3	High Exposure	0.34 - 0.38	2	Moderate Exposure
G284	North Pacific Open Bog & Acidic Fen	8 - 11	3	High Exposure	0.34 - 0.40	2	Moderate Exposure
G851	North-Central Pacific Lowland Riparian Forest	8 - 11	2 - 3	Moderate - High Exposure	0.34 - 0.40	2	Moderate Exposure

Group Code	USNVC Group	EX4. Summer Maximum Temperature			EX5. Precipitation Drought in Summer		
		Temperature (°F)	Score	Rating	Likelihood of Change	Score	Rating
G853	North-Central Pacific Maritime Lowland Swamp	8 - 11	2 - 3	Moderate - High Exposure	0.36 - 0.40	2	Moderate Exposure
G507	North-Central Pacific Montane Riparian & Seepage Swamp	9 - 11	2 - 3	Moderate - High Exposure	0.33 - 0.38	2	Moderate Exposure
G529	North Pacific-Columbia Plateau Vernal Pool	10 - 11	2 - 3	Moderate - High Exposure	0.25 - 0.38	1 - 2	Low - Moderate Exposure
G515	Rocky Mountain Acidic Fen	11	3	High Exposure	0.30 - 0.36	2	Moderate Exposure
G516	Rocky Mountain Circumneutral-Alkaline Fen	11	3	High Exposure	0.25 - 0.36	1 - 2	Low - Moderate Exposure
G526	Rocky Mountain-Great Basin Lowland-Foothill Riparian Shrubland	11	3	High Exposure	0.25	1	Low Exposure
G506	Rocky Mountain-Great Basin Montane Riparian Forest	11	2 - 3	Moderate - High Exposure	0.24 - 0.36	1 - 2	Low - Moderate Exposure
G505	Rocky Mountain-Great Basin Swamp	11	2 - 3	Moderate - High Exposure	0.24 - 0.36	1 - 2	Low - Moderate Exposure
G525	Temperate Pacific Freshwater Mudflat	8 - 10	3	High Exposure	0.34 - 0.38	2	Moderate Exposure
G499	Temperate Pacific Salt Marsh	8 - 10	3	High Exposure	0.34 - 0.38	2	Moderate Exposure
G373	Temperate Pacific Seagrass Bed	8 - 10	3	High Exposure	0.34 - 0.38	2	Moderate Exposure
G517	North Pacific Freshwater Wet Meadow & Marsh	8 - 10	2 - 3	Moderate - High Exposure	0.34 - 0.38	2	Moderate Exposure
G322	North Pacific Wet Shrubland	8 - 11	2 - 3	Moderate - High Exposure	0.33 - 0.40	2	Moderate Exposure
G521	Pacific-Rocky Mountain Montane Wet Meadow & Marsh	9 - 11	2 - 3	Moderate - High Exposure	0.24 - 0.40	1 - 2	Low - Moderate Exposure
G520	Pacific-Rocky Mountain Subalpine-Alpine Snowbed & Wet Meadow	10 - 11	2 - 3	Moderate - High Exposure	0.33 - 0.40	2	Moderate Exposure
G527	Western Montane-Subalpine Riparian & Seep Shrubland	9 - 11	2 - 3	Moderate - High Exposure	0.24 - 0.40	1 - 2	Low - Moderate Exposure

Group Code	USNVC Group	EX4. Summer Maximum Temperature			EX5. Precipitation Drought in Summer		
		Temperature (°F)	Score	Rating	Likelihood of Change	Score	Rating
G544	Western Temperate Freshwater Aquatic Vegetation	8 - 11	2 - 3	Moderate - High Exposure	0.24 - 0.40	1 - 2	Moderate - High Exposure

Table C-5. Sea Level Rise exposure metrics for all assessed USNVC groups.

Group Code	USNVC Group	EX6. Sea Level Rise	
		Score	Rating
G531	Arid West Interior Freshwater Marsh & Wet Meadow	NA	NA
G796	Central Rocky Mountain Lowland & Foothill Riparian Forest	NA	NA
G538	Desert Alkaline-Saline Marsh & Playa	NA	NA
G537	Desert Alkaline-Saline Wet Scrub	NA	NA
G385	North American Pacific Intertidal Algal Flat	4	Very High Exposure
G285	North Pacific Circumneutral-Alkaline Fen	NA	NA
G610	North Pacific Maritime Wooded Bog & Poor Fen	NA	NA
G284	North Pacific Open Bog & Acidic Fen	NA	NA
G851	North-Central Pacific Lowland Riparian Forest	NA - 1	NA - Low
G853	North-Central Pacific Maritime Lowland Swamp	NA - 1	NA - Low
G507	North-Central Pacific Montane Riparian & Seepage Swamp	NA	NA
G529	North Pacific-Columbia Plateau Vernal Pool	NA	NA
G515	Rocky Mountain Acidic Fen	NA	NA
G516	Rocky Mountain Circumneutral-Alkaline Fen	NA	NA
G526	Rocky Mountain-Great Basin Lowland-Foothill Riparian Shrubland	NA	NA
G506	Rocky Mountain-Great Basin Montane Riparian Forest	NA	NA
G505	Rocky Mountain-Great Basin Swamp	NA	NA
G525	Temperate Pacific Freshwater Mudflat	1	Low
G499	Temperate Pacific Salt Marsh	4	Very High Exposure
G373	Temperate Pacific Seagrass Bed	4	Very High Exposure
G517	North Pacific Freshwater Wet Meadow & Marsh	NA	NA

Group Code	USNVC Group	EX6. Sea Level Rise	
		Score	Rating
G322	North Pacific Wet Shrubland	NA	NA
G521	Pacific-Rocky Mountain Montane Wet Meadow & Marsh	NA	NA
G520	Pacific-Rocky Mountain Subalpine-Alpine Snowbed & Wet Meadow	NA	NA
G527	Western Montane-Subalpine Riparian & Seep Shrubland	NA	NA
G544	Western Temperate Freshwater Aquatic Vegetation	NA	NA